

Article

Modeling and Visualizing Smart City Mobility Business Ecosystems: Insights from a Case Study [†]

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Abstract: Smart mobility is a central issue in the recent discourse about urban development policy towards smart cities. The design of innovative and sustainable mobility infrastructures as well as public policies require cooperation and innovations between various stakeholders—businesses as well as policy makers—of the business ecosystems that emerge around smart city initiatives. This poses a challenge for deploying instruments and approaches for the proactive management of such business ecosystems. In this article, we report on findings from a smart city initiative we have used as a case study to inform the development, implementation, and prototypical deployment of a visual analytic system (VAS). As results of our design science research we present an agile framework to collaboratively collect, aggregate and map data about the ecosystem. The VAS and the agile framework are intended to inform and stimulate knowledge flows between ecosystem stakeholders in order to reflect on viable business and policy strategies. Agile processes and roles to collaboratively manage and adapt business ecosystem models and visualizations are defined. We further introduce basic categories for identifying, assessing and selecting Internet data sources that provide the data for ecosystem models and we detail the ecosystem data and view models developed in our case study. Our model represents a first explication of categories for visualizing business ecosystem models in a smart city mobility context.

Keywords: business ecosystem; collaborative modeling; ecosystem visualization; group modeling; crowd-based modeling; smart city; digital platform; digital infrastructure; data governance

1. Introduction

The digital transformation—and its accompanying changes—have long reached cities including their outskirts and rural satellites, and are expected to provoke “(fundamental) changes to traditional local economic structures” [1]. Actively integrating its prospective advancements into city infrastructures can enable cities to become what is commonly termed *smart cities* [2,3]. Smart cities are a recent vision in urban development policy of novel technology-based infrastructures to improve all facets of urban life [4]. It is often considered as a possible solution to challenges cities are confronted with, such as urbanization, migration, pollution, as well as changes in the demographic structure of societies, and climate change, which parallel the societal task to develop sustainable and humane technologies and lifestyles [5–7].

Due to its promise and potential, the concept of smart cities has increasingly gained attention of policy makers, citizens, researchers, and entrepreneurs [8]. In 2018, the European Commission published the definition of a smart city as “a place where traditional networks and services are made more efficient with the use of digital and telecommunication technologies for the benefit of its inhabitants and business” [9]. Technology, thus, can be considered as a potential enabler of smart cities [10]. The facets of a smart city are diverse, as digital technologies are used to include citizens in governmental processes and decisions (“smart governance”), to measure air quality or noise level (“smart environment”) or to enhance digital services in vehicles, traffic systems, and infrastructure (“smart mobility”) [11], to name just a few. Thereby, smart mobility is often recognized as the most common indicator of smart cities [12].

One proposed feature of smart mobility is a digital infrastructure for transportation or mobility that supports work and leisure travel and alleviates the challenges of an urban commute. *Digital mobility infrastructures* in smart cities are envisioned to integrate applications such as big data, cyber-physical systems, embedded systems, smart objects, and smart traffic control that intend to create ‘intelligent’, ‘ubiquitous’, or ‘smart’ environments including for instance location-based services. The design, integration, and implementation of a digital mobility infrastructure require coordination between entities from industries such as logistics, automotive, and government. Hence, beyond the infrastructure, a business ecosystem of multiple firms, organizations and stakeholders can be envisioned, all collaborating to enable or improve urban mobility [13].

Understanding the evolution process of such mobility business ecosystems is instrumental for developing public policies, for taking strategic decisions about business and technology partnerships, or for identifying gaps in the services provided to citizens and businesses as service customers [14]. Hence, the proactive management of the business ecosystem is gaining relevance for firms, as well as city authorities [14]. Particularly, for attaining a competitive edge, firms have to adapt their competencies and to identify complementary business partners and services relative to their specific position in the ecosystem [15].

This approach to understanding and managing ecosystems is aided by *business ecosystem models*, which can be considered as IS-embedded network resources [16], i.e., network-level, shared resources that support the creation of value propositions for all involved stakeholders as users of the model. In addition—and based on ecosystem models—*visualizations of ecosystems* have proven to enable ecosystem stakeholders to make better-informed decisions [17–19]. In the context of visual decision support, visual analytic systems (VAS) have been proposed and evaluated to leverage related benefits [20,21]. These systems allow addressing needs and demands of diverse user groups through different views and types of visualizations (layouts). VAS system architecture comprises elements for interaction of users, for interpreting the visual output, and for generating meaningful reports [21]. In the context of mobility business ecosystems, shared-use VAS that inform and configure shared platforms and infrastructures are potentially valuable for the entire ecosystem [22], however, case studies on VAS use for business ecosystem-aware management in smart city contexts are lacking so far.

One success factor of visualizing ecosystems is the availability of *ecosystem data* [21]. Ecosystem data comprises (a) technology-related data, such as available services, technological standards and platforms, monitoring data sources, (b) business-related data, such as information about service providers, their strategies, partnerships, offered solutions and cooperative initiatives, as well as (c) market-related data, such as regional coverage of services, user types (commuter, tourist etc.), or use patterns of mobile service apps. This data is input to ecosystem experts and data scientists who collaboratively evaluate and interpret it to create tailored visualizations. These allow to visualize the past development of the considered ecosystem and enable stakeholders to analyze present structures, e.g., which company positions itself as key player within the ecosystem [23].

Research addressing ecosystem models and visualizations has used sets of data collected from commercial databases on business and economic data or drawn from social or business media [14,23].

The required variety of data sources effects extensive data collection efforts, also requiring editorial revision of collected data. Data evaluation is, therefore, often executed only for a specific timeframe, resting on static data sets. As the structure of mobility ecosystems is emerging over time, the VAS ecosystem model, comprising data model and view model which are used to generate and visualize structures, must be adaptable to address changing data sets. Regarding the data model, e.g., new service providers must be linked to the right types of services or positioned in the market but can also constitute new types of firms or exhibit new kinds of relationships that subsequently need to be created in the data model. Regarding the view model, in general-purpose VAS, visualizations are often not adaptable without high effort. Thus, the view model needs to have the capability to adopt new structures originating from the data model in-use.

In addition to these aspects concerning data sources and technical requirements, the data collection, editing and visualization processes face further challenges. Analyzing business ecosystems is principally impossible to achieve for one single stakeholder because of the abundance and complexity of processes and data that would need to be observed, recorded, documented, or otherwise be visualized. Incorporating various groups of stakeholders can address this challenge of complex and heterogeneous data sources and business/technology contexts. As this editing process generates the input to the visualization process, both processes need to be linked within the VAS in order to provide high flexibility for interacting and interpreting with the help of the visualization user interface, to define relevant key indicators and to create tailored reports.

Our research contributes to the aforementioned challenges in two ways by using the design science paradigm [24,25]. Firstly, based on our own software engineering design work, we have developed and prototypically implemented a visual analytic systems (VAS), which we refer to as *Business Ecosystem Explorer (BEEEx)*. BEEEx allows to collect, aggregate and map data about the ecosystem collaboratively, to define analytic structures and to create and adapt multiple types of views in-use. It thus provides a customizable instrument for different ecosystem stakeholders as users of the system and offers a framework for understanding emerging structures of business ecosystems. Secondly, we describe an *agile process to collaboratively manage and adapt business ecosystem models*—collecting, editing and visualizing data to provide customized visualizations for different stakeholder needs. We demonstrate the utility and efficacy of these two design artifacts through a case study of a smart city initiative. We provide insights on how relevant data can be collected using Internet data sources, and we showcase significant parts of the ecosystem data model that can inform other smart city initiatives. We also discuss how ecosystem visualizations enable knowledge flows between different stakeholder groups within a mobility business ecosystem.

2. Related Work

2.1. Business Ecosystem Modeling and Ecosystem Data

James Moore introduced the term business ecosystem in the 1990s using a metaphor from biology [26]. He defined it as “an economic community supported by a foundation of interacting organizations and individuals—the organism of the business world. This economic community produces goods and services of value to customers, who are themselves members of the ecosystem” [26] (p. 26). Until today, research on this concept has been extensive [27] focusing on different aspects of business ecosystems, e.g., the technological aspect of a core technology or a technological system in the center of the business ecosystem [28,29], the network aspect [30,31] or interconnectedness/interdependencies [32,33], to name just a few. Sako [34] defined three meta-characteristics of business ecosystems—sustainability, self-governance, and evolution—to contribute to a better distinction of the ecosystem concept from clusters or networks. Thereby, he focuses on “value-creating process (. . .) rather than . . . industrial sector”.

The boundaries, characteristics and the evolving dynamic structure [35] of a business ecosystem are not only affected by the different roles of participating organizations and stakeholders—such as suppliers, distributors, outsourcing firms, makers of related products or services, technology

providers, and a host of other organizations [36]—but by the fact that firms continuously enter and leave the ecosystem [20]. Current approaches focus on frameworks to grasp the scope of ecosystem complexity [37,38], or on visualization to understand emerging structures and patterns [37,39].

Our conceptualization of the business ecosystem model takes into account both, the static network of entities, e.g., firms, technologies and services, as well as the dynamic network characteristics, i.e., the relationships between entities and activities, all changing over time. Thereby, we consider various types of entities of varied legal forms and company sizes, all participating in and influencing the ecosystem, such as corporations, public sector organizations, universities, research facilities and other parties [35]. These entities of the ecosystem are linked via different kinds of relationships, such as collaborations, co-funding, or ownership. To contribute to a better understanding of the ecosystem, the business ecosystem model has to incorporate all these elements. Thereby, as the modeling aim is to support business ecosystem stakeholder in their ecosystem-related tasks, the requirements put forward by these stakeholders define which entities and relationship types need to be modeled, which (visual) views are relevant, and which insights are vital for generating and adapting the model.

Past research has shown that visualizations of business ecosystems on basis of such models indeed support decision-makers in their ecosystem-related tasks and decisions [17–19]. Visualizing data can help stakeholders to derive value from ecosystem data, such as spotting anomalies or identifying keystone and niche players of the ecosystems [40].

Ecosystem data can be considered to be ‘large and heterogeneous’ [23]. When focusing on the business aspect of the ecosystem, relevant information includes business partners, competitors, partnerships and offered solutions, cooperative initiatives, as well as start-ups and their strategies [41]. This information is spread over a wide range of sources, such as publicly accessible databases, enterprise or institutional presences and publications, or blogs and news articles. Successfully collecting ecosystem data sets distinct limits concerning the value and usefulness of visualizations in the ecosystem analysis or business development [13]. However, no solution has been determined so far that might resolve the issue of how comprehensive amounts of ecosystem data can be obtained and validated for their usefulness and efficacy towards ecosystem-related tasks and decisions [37,42].

In addition to including various data sources for a broad perspective and involvement of diverse aspects of the ecosystem, it is important to include various types of stakeholder groups in the modeling process. These groups provide for both, diverse ways to access ecosystem data, and own interests to use the ecosystem model. Depending on the ecosystem in focus, these groups can range from company representatives in case of a company-internal business ecosystem modeling approach, to boards, associations’ interest groups, or online communities.

2.2. Business Ecosystem Visualization

Park et al. [21] presented a visual analytic system (VAS) to nurture the *perception* of business ecosystems. It addresses three salient design requirements related to distinct complications in the context of supply chain ecosystems. Their research on modeling, visualizing and analyzing different types of business ecosystems [17,19,20,35,37,38] showcases that VAS empower their users to interactively explore the network relationships by offering multiple views within an integrated interface, as well as data-driven analytic features. The authors suggest and test five visualization types (layouts) to visualize the dynamic networked structures of their problem context.

These layouts include force-directed layout (FDL), tree map layout (TML), matrix layout (MXL), radial network/chord diagram (RCD), and modified ego-network layout (MEL). Interactive features, such as clicking, dragging, hovering, and filtering, are essential parts of the visualizations. These layouts are used by us as the baseline for the design of our own VAS in our problem context. Nonetheless, further designs exist, such as bi-centric diagrams that visualize the relative positioning of two focal firms [20,23] or cumulative network visualizations [19].

The explanatory power of any layout rests on the credibility and informative value of the underlying data. Current research on ecosystems at large uses data-driven approaches, i.e., sets of

data are collected from commercial databases on business and economic data, or drawn from social or business media [19,20]. Implications of this approach are, first, the VAS users need to understand the relevance and quality of sources that can provide data for the ecosystem model, and second, the guiding questions and rules for the visualizations need to be transparent to the users. When both the model and the visualizations can be adapted to host diverse business perspectives and intentions, this allows the diverse set of VAS users to create their own VAS instances in order to facilitate setting the focus on distinct data sources and structures.

2.3. Smart City Mobility Ecosystems from an Information Systems Perspective

Recently, researchers have focused their efforts on the challenges for ecosystem formation that appear in various contexts, such as technology, e.g., the Internet of Things (IoT) [20], or policy, e.g., emerging smart cities [38].

When focusing on smart city mobility ecosystems, research on ecosystems is still in a nascent stage [13]. In smart city mobility ecosystems there are at least three domains that come into play—technical, governance, and human. The technical domain addresses trends such as big data [42], cyber-physical and embedded systems [43], smart traffic control [44], etc., and enables new application fields for information technologies. Location-based services are one example for providing mobility users with information about near-by mobility offers, creating an ‘intelligent’ or ‘smart’ environment [10,44]. In the governance domain, information systems (IS) provide for means to influence the mobility behavior of citizens, e.g., by incorporating air quality measurements in the app-based routing [45]. In the human domain, IS can foster creativity and learning and, thus, promote the development of knowledge-based urban societies and economies [46].

For the smart city mobility ecosystem, all three domains come into play providing new markets and new spheres of activity for those firms and organizations (including cooperatives, communities, municipalities, public transportation services etc.) that provide transportation and mobility-related information services, as well as infrastructure means and devices [2,38].

Extant research has suggested that smart city mobility ecosystems are particularly open to engage citizens within crowdsourcing efforts [46]. Since platforms, provided services, and customer response are spatially focused, engaging different stakeholder groups to actively participate becomes a core strategic factor. In this vein, the power of visualizing (emergent) structures to identify novel value propositions becomes apparent [47] (p. 45).

Novel technologies that offer crowd-sensing capabilities could be contributive to becoming better aware of the mobility infrastructure in real-time [48]. User-generated data, including location monitoring data or usage data from mobility service or social apps, can inform the analysis of service use or mobility-related challenges such as traffic jams, preferred routes etc., which would otherwise be difficult to discover [49].

On the policy side, visualizations serve the information collection process that underpins policy development in context of regional economic renewal and transformation [50]. This includes understanding agencies [51] or identifying potential avenues for innovation or regional progress [52–54]. On the business side, visualizations can contribute to awareness about the ecosystem to understand a firm’s competitive position, to recognize platform market convergence or emerging structures, to support strategy or business model development or to aid business development, e.g., by recognizing lacking services [55].

3. Method and Design Artifacts

We have adopted a design science research approach [24,25], as this perspective suits our research context of a case study and the objective to create and test a visual analytic system (VAS). In the metropolitan region in focus of our case study, the structures of the mobility ecosystems are currently emerging as effected by public authorities who re-evaluate their policy and regional development activities, and by businesses trying to co-shape the evolving mobility ecosystem. Our design artefacts

are (1) a visual analytic systems (VAS), the Business Ecosystem Explorer (BEEEx), which is particularly instrumental to provide tailored visualizations to different stakeholder groups, supporting them in their business- or policy-related tasks and decisions, and (2) an agile approach to ecosystem modeling. In the following, we present the design of these artifacts and argue in which way they respond to the challenges in ecosystem modeling.

3.1. Visual Analytic System (VAS): Business Ecosystem Explorer (BEEEx)

For the design of our Visual Analytic System (VAS) we extend on a software engineering framework that technically resides upon the ‘Hybrid Wiki’ approach suggested by Reschenhofer et al. [56], and which from a use perspective allows to follow an agile process to create and adapt the model that is used by the VAS to represent ecosystem entities and structures (see Section 3.2). This framework addresses the dynamic structure of business ecosystems as it supports the evolution of the model as well as its instances at runtime by stakeholders and ecosystem experts, i.e., users without programming knowledge or skills. We have implemented the framework as Business Ecosystem Explorer (BEEEx) on basis of an existing integrated, adaptive, collaborative Hybrid Wiki system. The latter system not only serves as a Knowledge Management System (KMS) application development platform, including features necessary for collaboration, data management, and decision support, but which also implements other features such as tracing back changes to the responsible user, including the time and date the change was made. In our case study, we have used its underlying Hybrid Wiki metamodel to create business ecosystem models.

The Hybrid Wiki metamodel comprises the following model building blocks: *Workspace*, *Entity*, *EntityType*, *Attribute*, and *AttributeDefinition*. These concepts structure the model inside a *Workspace* and capture its current snapshot in a data-driven process (i.e., as a bottom-up process). An *Entity* consists of *Attributes*, which have a name, can be of different data types (i.e., strings, numbers, references on other *Entities*), and are stored as key-value pairs. *Attributes* can be instantiated at runtime, and this helps to seize structured information about an *Entity*. The *EntityType* facilitates grouping related *Entities*, such as organizations or persons. It consists of several *AttributeDefinitions*, which can define validators for the *Attributes* of the corresponding *Entities*, like multiplicity or link value validators, which in turn leads to increased cohesion among the *Attribute* values.

3.1.1. Business Ecosystem Explorer: Data and View Models

BEEEx relies on two models that each provide features for creation and adaptation, first, the ecosystem *data model*, and second, the ecosystem *view model*. Both models are encoded using the Hybrid Wiki metamodel.

The ecosystem data model contains the *EntityTypes* of relevance for the business ecosystem in focus. The ecosystem view model is encoded as one *EntityType* called “visualizations”. Each visualization has two elements: the first element is the link between the data model and the visualizations. The second element is the specification of the visualizations using a declarative language. Five main building blocks enable static and dynamic visualization features; these are (a) data, including data but also all data transformations; (b) marks, covering the basic description of the visualized symbols, e.g., shape and size of a node; (c) scales, containing visual variables, such as the color coding; (d) signals, including the different interaction options, e.g., dragging and dropping of entities; and in some instances (e) legends.

The metamodel allows making changes to the data and view models at runtime, thus updating the visualizations instantly when the data model is changed by, e.g., adding new categories or changing or deleting categories. Figure 1 gives an example of categories of organizations and their types, which both can be adapted at runtime.

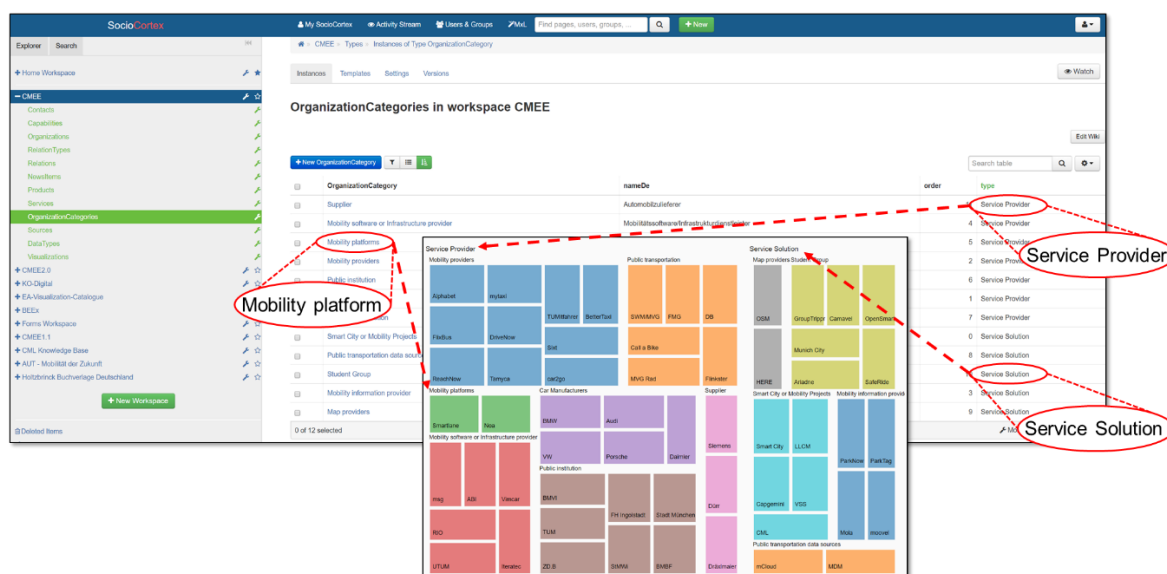


Figure 1. User interface of the Business Ecosystem Explorer (BEEEx) with list of *categories* and *types*, and conversion to tree map layout (TML) [41].

3.1.2. Business Ecosystem Explorer: Views

BEEEx currently offers six different views: a landing page, a list of all entities, a relation view, a detailed view with entity information, a visualization overview, and several visualizations (layouts). All views include a menu bar at the top of the page, which provide links to the other views, as illustrated in Figure 2. The visualizations are described in detail in the context of our case study report in Section 4.3, Table 3, and Figure 5.

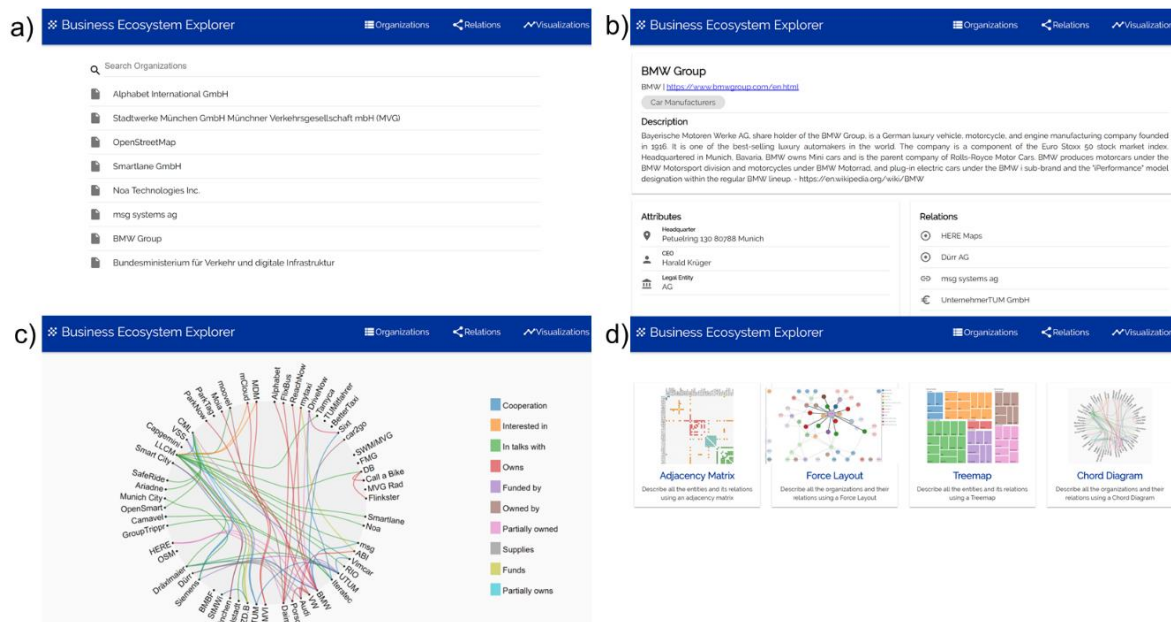


Figure 2. Business Ecosystem Explorer (BEEEx) views to navigate the business ecosystem model (adapted from [41]).

3.2. Agile Approach to Ecosystem Modeling

3.2.1. Agile Modeling Process and Roles

To model business ecosystems in a collaborative process, we propose the generic, agile modeling process depicted in Figure 3. The process consists of five phases overall.

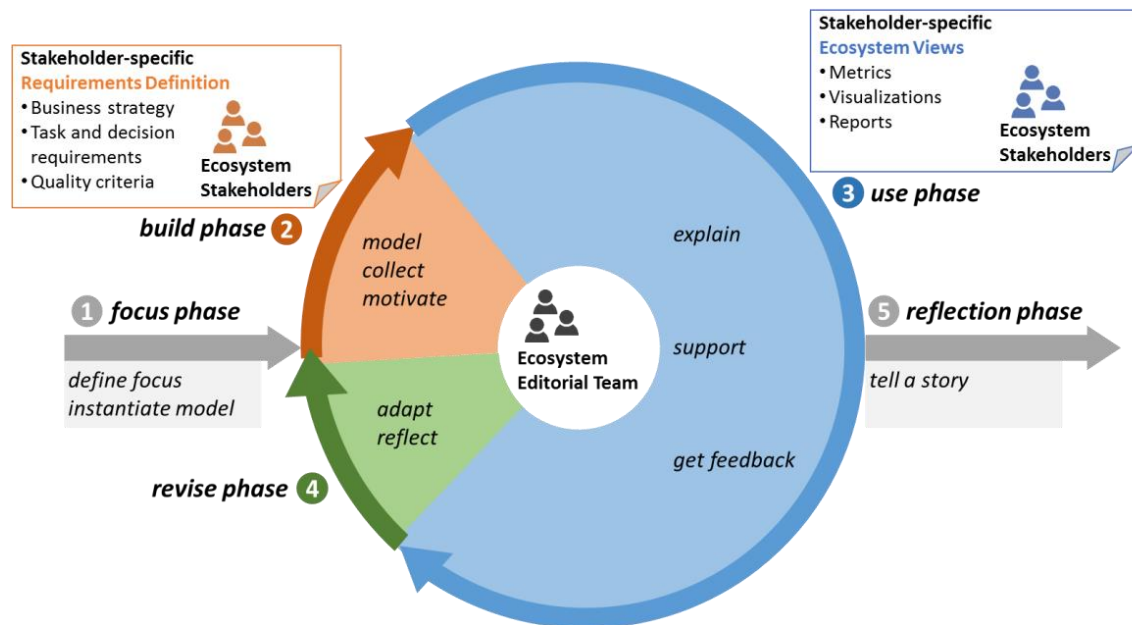


Figure 3. Agile process to collaboratively manage and adapt the business ecosystem model (adapted from [41]).

In an initial *focus phase* (process step no. 1 in Figure 3), first, the focus of the business ecosystem is defined, e.g., the ecosystem established around a technology platform, the ecosystem of a particular market exploiting specific digital technologies, or the ecosystem around one focal firm. Second, the model is instantiated, for which both the data model and the view model are set up.

The next three phases of the process are iteratively executed. The *build phase* (2) comprises activities to motivate creation and use of the VAS, to collect data about/from the ecosystem, and to carry out the modeling. Basic requirements for engaging in an ecosystem modeling initiative stem from the core stakeholders such as the executive management, strategy boards, business case owners or project teams of enterprises, entrepreneurs, representatives of public authorities, institutions, or organizations, or other domain experts. Together with these experts, specific questions about the ecosystem, its development or structures are formulated as basis of a stakeholder-specific requirements definition. These questions mirror the business or policy strategies that undergird the respective intentions and initiatives at large as well as specific task and decision requirements. They also lead to quality criteria that guide the further modeling process (see also Section 4.1) (for reasons of simplicity, we further apply the use scenario of an enterprise, but roles will correspond to use in a public policy maker scenario, too). These requirements are taken up by a team (role) we named the Ecosystem Editorial Team. This role is responsible for collecting data and executing the modeling (it is conceivable that for public use, a separate, public or third party funded editorial office is created that overlooks and eventually investigates on ecosystem data sources).

For the initial instantiation, company internal information systems can be drawn upon as data sources, providing already collected information about competitors, business partners, etc. Additionally, each stakeholder group is motivated to implement their specific knowledge documented locally and to communicate the sources used to gather information. Within the iterations of the build phase, the Ecosystem Editorial Team orchestrates continuous data collection from these sources as

well as from news feeds, blogs, etc., both manually and eventually also automatically. For instance, automatic news feed evaluation can be included to enrich the database. For public use, in the build phase both international data sources, such as Crunchbase (www.crunchbase.com) or AngelList (angel.co), as well as national ones, e.g., Gründerszene (gruenderszene.de) in Germany, can be consulted. During this phase, the stakeholder groups should be kept motivated to contribute with information whenever possible. In the subsequent iterations, data gathering can extend to crowdsourced data provided by the stakeholders using previously defined metrics, visualizations, and reports.

In this phase, each stakeholder group retains specific requirements towards both, understanding the ecosystem as well as the functioning and use of the VAS. In our case study, for the BEEx prototype, requirements from several stakeholder groups were collected; each group provided particular demands with regard to relevant entities, and creation of views. For instance, legal department representatives were interested in legal forms and business relationships of business partners, while strategy teams focused on platforms and technologies related to ecosystem members and cooperative initiatives, to inform the search for potential future business partners. In our case study, the requirements were initially collected in workshops led by the Ecosystem Editorial Team with each stakeholder group. In later iterations of the build phase, the requirements are potentially gathered with help of the VAS through an online process only.

The *use phase* (3) intends to stimulate the formation of stakeholder-specific ecosystem views; it covers representation of the created model within different visualizations (layouts), interactions between users and the layouts to analyze the ecosystem, preparation of reports, and feedback to the Ecosystem Editorial Team in order to fine tune or revise the model and related metrics such as key values about centrality or connectedness of an entity. Reports play an important role in the communication process [57] and for explanation, as they contain the interpretation of data and visuals by the domain experts, executive management or other business stakeholders as users. This interpretation at a specific point of time serves as input to further analysis and revision, and helps to follow the emergence of structures or patterns at a later stage.

The *revise phase* (4) comprises the reflection on achieved results, on model validity and on provided visuals as well as the adaptation of model and requirements. In this phase, additional input from external domain experts can be sought depending on upcoming tasks [16]. The Ecosystem Editorial Team plays a key role in this process phase, and consequently its modeling expert members require some particular domain knowledge about modeling. The team should also be capable of managing the various stakeholder groups, deliver stakeholder-specific visualizations and safeguard the process cycle. The task of ecosystem experts holding domain knowledge about business or regional factors etc., is to collect information from the ecosystem and prepare it in the right format as content of the ecosystem model.

Due to the mentioned requirements for cooperation and collaboration put forward by the modeling process, in our case study we have implemented the VAS on the basis of an integrated, adaptive collaborative work system. Its collaborative features together with the agile approach to collaborative modeling allows to step-by-step integrate all stakeholders' requirements to the ecosystem model and visualizations. The model thus grows with increasing demands and found solutions, i.e., visuals that comprise selected entities and relationships to answer specific questions about the ecosystem. This integrative aspect showed particularly relevant in our case study where one single digital platform was to be developed for use by a larger ecosystem initiative. Multiple stakeholders including public and private organizations subsequently became users of the ecosystem model on a single digital platform.

In the *reflection phase* (5) the created visualizations are used to "tell a story," i.e., to extract knowledge about the ecosystem that contributes to a better understanding of the ecosystem in focus, such as spotting anomalies or identifying keystone and niche players of the ecosystems [39]. This can take the form of reports to motivate stakeholders (phase 2) or to inform the public.

3.2.2. Adoption and Agility Aspects

From our field test, we have learned that it is vital to ensure involvement of diverse stakeholder groups, and to keep them motivated to discuss and explore the model across process phases and iterations. In this respect—and validating previous research—we have experienced that it is helpful to present an early version of the business ecosystem model and visualizations to address specific demands [58]. Further, we have noticed that the availability of varied visualizations can stimulate cross-contextual thinking, which might lead to formulation of new key values in interpreting the ecosystem, e.g., transitive relationships that express the indirect closeness between entities.

As a result, we suggest that each of the phases should be implemented as interactive and collaborative processes to enable early adaptation and validation of formulated requirements [58]. In order to increase usability and adoption of the system by different stakeholders, we have experienced that adapting and evolving the business ecosystem model and visualizations without having software development skills plays a central role. This affords that the collaborative modeling process is continuously supported by application systems that allow the end-users—i.e., users without software development skills—to modify the business ecosystem model and visualizations at run-time, i.e., without the need to stop and recompile the system to integrate new functionalities. In this sense, we use the term ‘agile’ to characterize the way in which the process from requirements definition to visualization and feedback should be managed.

4. Case Study: Modeling and Visualization of a Smart City Mobility Business Ecosystem

In the following, we report findings from our case study, which is part of a smart city mobility initiative pursued by a European city with a population of more than 2.5 m in its urban area and more than 5.5 m in its metropolitan region. The mobility business ecosystem is anticipated to embrace more than 3.000 firms in the automotive, traffic and logistics sectors residing in the urban area and more than 18.000 firms in these sectors in the metropolitan region.

In parallel to the initiative, the BEEEx software prototype (as described in Section 3) was developed. In an iterative process, the phases of ecosystem analysis, software engineering, feedback with ecosystem stakeholders and public authorities as well as suggestions of visualization techniques were carried out. During the study, the researchers maintained a high interaction frequency with all project partners and ecosystem stakeholders. Throughout the three-year project, more than 30 workshops and numerous feedback talks were conducted. In these workshops, issues such as inter-firm relations between ecosystem participants, changes observed in the ecosystem, governance issues and other concerns were discussed. These discussions informed the modeling and visualization process, following previous research that has suggested a strong correlation between the effectiveness of visualization methods, the ‘problem’ representations and users’ mental models [17].

The discussion with ecosystem stakeholders reveals their mental models in terms of task and decision requirements, which provide the objectives for identifying, modeling and visualizing relevant entities and their relationships present in the ecosystem. Data complexity, characteristics of decision tasks and particularities of stakeholders all influence decision performance in the context of business ecosystem analysis [17]. Our design of the BEEEx software prototype, thus, intends to allow for integrating these factors.

The project intended to support ecosystem stakeholders who are already—or were about to become—engaged in a smart city mobility initiative with informative insights about the related ecosystem. A pre-assumption of the research team thereby was that all participating stakeholder groups—governmental institutions, mobility initiatives, start-ups or established corporate organizations and the like—were eager to discuss, contribute to, and use the obtained project results and thus to influence the evolution of the business ecosystem by establishing an ongoing dialogue between them.

In the following account of our case study findings, we first describe the data collection process (Section 4.1), highlighting how to identify, assess, select and use Internet data sources to gather

an initial set of data describing the mobility business ecosystem. Then we detail the data model (Section 4.2) and the view model (Section 4.3), and particularly provide details on the building blocks of the implemented visualizations (layouts).

4.1. Data Collection

We used Internet data sources for the initial data gathering process, which was conducted by the Mobility Ecosystem Editorial Team. To ensure the fit of our set of selected data sources to the overall project objectives, early on in the project we included an individual ecosystem stakeholder representative in the assessment of data sources. As main user and beneficiary of the mobility business ecosystem visualization, we identified a publicly funded institution, established to support local collaboration and start-ups. One strategic objective of this institution is strengthening the mobility ecosystem by organizing mobility networking events and initiating and supporting innovative mobility projects in close collaboration between research and industry through co-funding. Mission and objectives of the institution provided an initial set of requirements for definition of quality criteria for data collection. As our implemented VAS, BEEEx, provided the capacity to adapt models in run time, we could iteratively adapt and extend quality criteria, allowing us to focus on stakeholder requirements and to disregard application system-specific requirements as necessitated in other VAS [59].

The overall data collection process we followed is pictured in Figure 4 and comprises of three steps, identification, assessment and selection, and data extraction, which we describe in detail in the following.

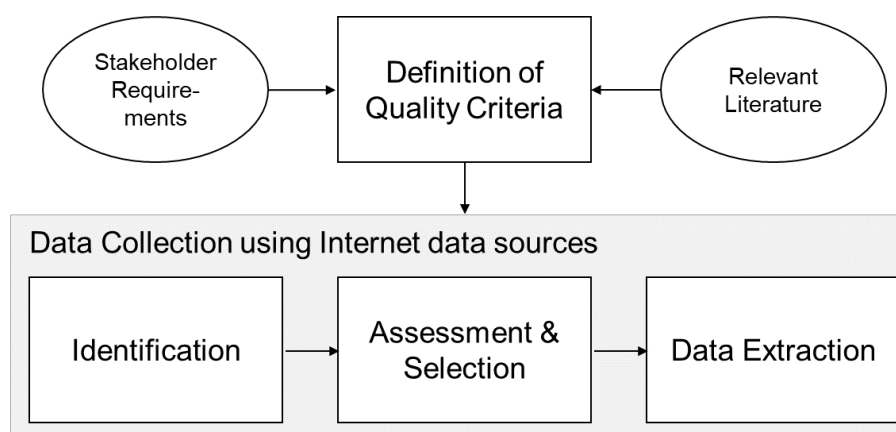


Figure 4. Process of data collection using Internet data sources (adapted from [59]).

4.1.1. Identification of Internet Data Sources

For the identification of Internet data sources, that provide information about the mobility ecosystem, we conducted an online search and consulted participants of the mobility ecosystem. Within the online search, to ensure a broad background of sources, different search terms were used within two search engines. They ranged from rather granular search terms like “connected car database”, “mobilität startup datenbank” (mobility startup database), or “blog über mobilität” (blog about mobility) to basic queries such as “company database” or “automotive database”.

The identified Internet data sources can be divided along three categories: The first category concerns databases comprising entities that offer products and services related to mobility. Depending on the focus of the database, the information provided ranges from a sole company name or a superficial categorization to more detailed information about each entity such as information about the headquarter location, the current CEO or a general description of the field of activity. In general, these databases offer access to their data either *open source*—meaning the data is freely accessible and reusable without an additional authorization step, *open source with enforced registration* (without charge), or as *proprietary data sources*, which require registration, authorization, and charge fees [59].

The second category comprises news feeds, blog posts, or web articles, which describe recent developments of the mobility ecosystem. Thereby, the blogs can target only mobility-related topics or address this topic as one among others in dedicated articles or posts. These sources can be categorized regarding their accessibility analogous to the ones mentioned above, open source, open source with registration, or proprietary data sources.

The third category covers information published online by mobility ecosystem stakeholders about themselves as part of their public web presence or in publicly accessible reports. Such information can range from public statements regarding their recent business development, to strategic corporate decisions, to listings of suppliers or collaboration partners, to name just some covered content. Within this category of Internet data sources, information is accessible without restriction or enforced registration. This category also comprises databases of established (publicly funded) networking organizations situated in the region of interest that do not necessarily focus on mobility issues, in our case study, for instance, Bayern International (bayern-international.de/en/). Such databases were identified during the Internet search or by consulted members of the mobility ecosystem.

4.1.2. Internet Data Source Assessment and Selection

Starting from the publicly funded institution we had identified as main user and beneficiary of the ecosystem visualizations, we collected requirements from this stakeholder within two interviews. Additional quality measures were extracted from existing research [59–62]. For our initial data collection, the identified Internet sources were evaluated using the following criteria: (a) *data access*—we focused on openly available Internet data sources; (b) *platform focus*—the data source should at least contain data that is relevant for a mobility business ecosystem within the scope of the smart city project; (c) *geographic focus*—the content of the source should contain data that is relevant for the local mobility ecosystem; (d) *data scope*—defining what kind of data is covered regarding (d1) *entities*—with attributes such as name, legal type, headquarter, CEO, description, and (d2) *relations*—with attributes such as type of relation, involved partners, date (in case of a funding); (e) *data extraction*—how easy can the relevant data be extracted from the source, and (f) *data validity*—can the source be trusted. All identified Internet data sources we also referred to later on provided information in either English or the local native language (in our case: German). Thus, an assessment based on the language was not conducted.

In total we selected 16 Internet data sources, which we collaboratively evaluated in workshops with the ecosystem stakeholder with respect to above criteria. In our case study, we only deployed sources that were accessible free-of-charge. We believe that for individual initiatives using fee-based data sources might be a beneficial addition, as such sources might also actively inform registered users about changes in the data.

4.1.3. Data Extraction

Depending on the Internet data source, the extraction process of data varies. Databases often provide download features for their data, or a subset, in a compressed form, e.g., as comma-separated values (csv) or Excel tables (xlsx). As a preliminary ecosystem data model is created prior to the data gathering process step, the data downloaded from databases have to be adapted to the model. In our case study, we manually extracted the data from blogs, news feeds, and company public web sites. We believe that especially for databases comprising blogs and news feed about the ecosystem in focus, the (semi-) automated extraction is an appropriate enhancement. An automation of this process could not only save valuable resources but could also enable (almost) real-time availability of the data and hence create possibilities for more advanced analyses of changes within the ecosystem. For instance, artificial intelligence (AI) mechanisms could be useful for distinct ecosystem actors such as financial analysts. From a more general perspective, if VAS usage turns into an established routine of a stakeholder, the automated extraction of data from news feeds and blogs would ensure an up-to-date dataset used for visualizing.

4.2. Data Model

In parallel to the identification of data sources and data collection, we started to categorize entities and their relations, in order to define the categories to be used in the visualizations. The data model implemented in BEEx enables users to filter for specific *organization types* or differentiating between *relation types* through coloring. By listing the categories defined in our case study—both for organizations and for their relations in Tables 1 and 2—we aim to provide a starting point for similar initiatives to identify categories of their primary interest or to enlarge the existing list with additional types to complete their view of the ecosystem in focus.

For our case study mobility ecosystem, we identified sixteen *organization categories*, which are described in Table 1.

Table 1. List of organization categories participating in the mobility business ecosystem.

Organization Category	Description	Organization Type
(Mobility) Data Provider	Entities bundling and providing (mobility) data to third parties.	Service Provider
Add-on Services	Additional service providers, such as mobility focused consultants or advertisement agencies, but also car tuners.	Service Provider
Car Manufacturer	Original equipment manufacturer with the focus of car production.	Service Provider
Energy Supplier	Companies involved in the production and sales of energy, including fuel extraction, manufacturing, refining and distribution.	Service Provider
Infrastructure Provider	Companies offering charging infrastructure for electric cars.	Service Provider
Institute & Initiative	Public organizations targeting research, innovation, technology and knowledge transfer within a specific region or industry field. Often active engage in networking activities.	Service Provider
Insurance	Companies offering protection from financial loss.	Service Provider
Mobility Provider	Organizations offering mobility in form of classic rental car services.	Service Provider
Parts Supplier	Companies producing automotive components, ranging from electric systems, interior equipment to car paint, which they supply to car manufacturers.	Service Provider
Platform & Connectivity Provider	Companies providing a platform enabling a two-sided market of developers and users to develop, provide and consume applications. In addition, service providers offering telephone and network services for customers to exchange information electronically.	Service Provider
Public Institution	Public institution responsible for funding but also regulations with a high influence in the market, but also research institutions.	Service Provider
Public Transport	Companies offering public transportation with buses, trains, trams, or metro trains.	Service Provider
Technology Company	Companies focusing on the developing and manufacturing of technology, or providing technology as a service.	Service Provider
Mobility Information Provider	Companies enabling mobility as a service by providing traveling information incorporating different modes of transportation. Often a strong link to mobility service providers exists due to the necessary interfaces between both services.	Service Solution
Mobility Service Provider	Companies offering mobility solutions that enable customers to consume mobility as a service, such as car sharing, bike sharing or ride sharing.	Service Solution
Project	A temporary (rather than permanent) undertaking that is carefully planned to achieve a particular aim. Can be carried out individually or collaboratively.	Service Solution

In mobility business ecosystems, mobility services such as car, bike or ride sharing are gaining more and more importance. Limited parking space, high cost of buying and maintaining private cars and improved availability of public transportation are amongst the reasons why the demand for mobility as a service increases. *Mobility as a Service (MaaS)* refers to the integration of various forms of transport services into a single mobility service accessible on demand [63]. Recently, *transportation network companies (TNCs)* reached particular popularity as mobility service providers through firms such as Uber, Lyft, or Gett, which connect private drivers using their own cars to passengers searching for a lift. TNCs introduced and leveraged a more user-centered view on mobility; and we took this as

an impetus to distinguish in our model between *service providers* covering all “traditional” organization types on the one hand, and *service solutions*, represented by mobility information providers, mobility service providers and projects on the other hand. With this distinction, the ecosystem can be analyzed regarding its realization or backlog adjusting to ‘digitized mobility’ from a user centered perspective addressing the need for MaaS.

As relations between these diverse entities within our mobility business ecosystem we identified six *relation types*. These types are described in detail in Table 2.

Table 2. List of relation categories between entities in the mobility business ecosystem.

Relation Types	Description
Cooperation	Entities collaborating towards shared services or products. The cooperation can be temporary or a long-term strategic one.
Funds	Granting of funds between two entities, usually during the initial start-up phase of one entity.
Membership	Entity is part of an initiative, institution or project.
Ownership	One entity having exclusive rights over another entity due to a legal belonging.
Partial Ownership	Several entities sharing the rights of another entity, the shares can be equal but also proportionate.
Supplied	One entity provides its service or product to another entity, which consumes it for its own service or product.

4.3. View Model

The view model implemented in our VAS, BEEEx, allows to configure diverse types of visualizations (layouts). In our case study, we used a declarative language to implement four layouts in order to visualize the collected data along the categories defined in the ecosystem data model. The layouts are detailed in Table 3. The according visualizations are displayed in Figure 5.

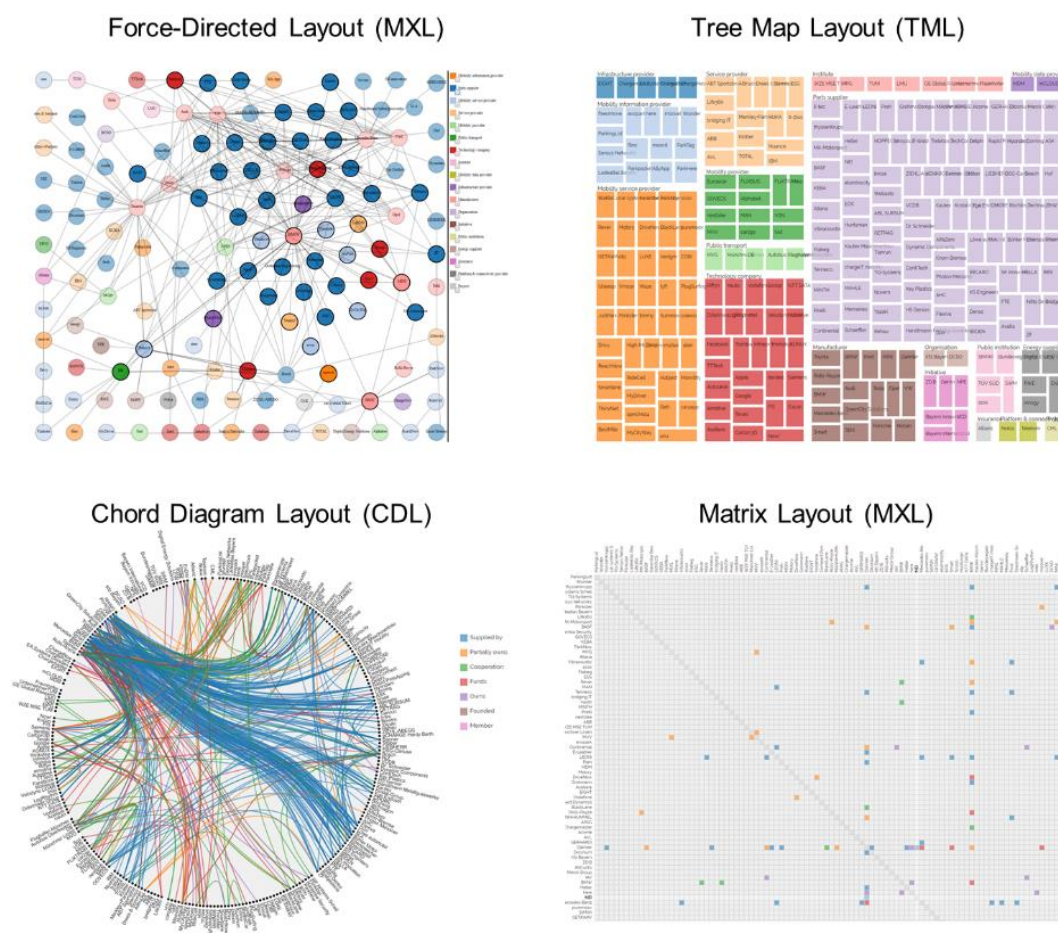


Figure 5. Visualizations of the smart city mobility business ecosystem of our case study using the Business Ecosystem Explorer (BEEEx) and data collected from Internet sources.

Table 3. Visualization building blocks.

	Visualization Building Blocks	Description
Force-Directed Layout	Data	All data visualized is documented in an object composed of nodes and links. The ecosystem entities are represented by nodes consisting of attributes, whereas relations between entities are documented as links connecting these nodes with a source, target and type attribute. The attributes describing the entities are ID, abbreviation, category, CEO, country, description, headquarter, logo, type and URL.
	Marks	The entity nodes are displayed as circles. Each node displays the company's abbreviation as text. The links are represented as straight lines always connecting two entities.
	Scales	The node color is set according to the ecosystem entity categorization. Each category is rendered with a particular color. The link line is identical for all types of relations.
	Signals	When hovering over a diagram node, it is highlighted by an extension of the node size. Additionally, the mouse pointer changes to emphasize that each node is clickable leading to a dedicated company side presenting more descriptive attributes.
	Legend	The color of the icons, i.e., the organization categories, are displayed including the option to select specific categories to be visualized.
Clustered Tree Map Layout	Data	The entities of the ecosystem are documented in a hierarchical data structure. Each element contains a reference to an ID, name, and parent, where applicable.
	Marks	Each ecosystem entity is represented as a rectangle in the according category. In each rectangle, the abbreviation of the entity is displayed and the text font is defined.
	Scales	The color of the rectangle is chosen depending on the entity's category.
	Signals	When hovering over a rectangle of the diagram this rectangle is highlighted by a brighter tone of the respective rectangle color and by a bold type company name. Additionally, analogous to the signals of the force-directed layout, the mouse pointer changes to emphasize that each node is clickable leading to the dedicated company side.
Chord Diagram	Data	The data documenting the business ecosystem entities is stored as described in the clustered tree map layout. This data is transformed to be visualized as arcs around the circle. Additional to this data and its transformation, an array documents the relations between the ecosystem entities. Each array entry thereby consists of a source, target and the type of relation.
	Marks	To achieve a circular layout, the coordinates are mapped from a Cartesian to a polar description. The text size of the company name is defined.
	Scales	To support the distinguishability of the different kind of links between ecosystem entities each type of relation is visualized with a respective color.
	Signals	When hovering over an entity on the arc of the circle this entity is highlighted by a bold type company name. Also, all relations of this entity are highlighted by a bold type curve whereas the remaining relations are grayed out. The entities the selected entity is in a relation with are also highlighted by a bold type company name. The mouse pointer changes to emphasize that each node is clickable leading to the dedicated company side.
Matrix Diagram	Data	The visualized data is documented identical to the force-directed layout. An object consisting of nodes and links. To achieve clusters inside the matrix, within the data transformation the entities are sorted and grouped.
	Marks	All cells of two entities not connected via a relation are colored gray. Additionally, the text font of the first column and first row, displaying the entities' names, are defined.
	Scales	In case a relation is available for two ecosystem entities, this cell is colored according to the type of relation.
	Signals	When clicking on a node label, i.e., an entity name in the first row or column of the matrix, the according row and column is highlighted by a darker gray color of all empty cells.

5. Discussion and Conclusions

5.1. Stimulating Knowledge Flows through Visualizations

Our learnings from exercising the iterative phases of the agile modeling process together with the various types of stakeholder groups suggest that visualizations stimulate knowledge flows within and between the involved stakeholders. These knowledge flows substantiate a central value proposition of VAS for ecosystem modeling initiatives. In Figure 6, we illustrate several stakeholder groups from our case study and their principal interactions with the ecosystem model and BEEEx. We found three particular groups of actors using and contributing to visualizations of the mobility business ecosystem:

First, a *Mobility Ecosystem Editorial Team*, which is strongly connected to the VAS (analogous to the generic description in Section 3.2). The team develops, maintains and markets the VAS for both public and private (for-profit) ecosystem visualizations, and eventually provides consulting services towards ecosystem members or policy recommendations towards city authorities. Therefore, the team gathers requirements and feedback of the other groups to deliver target visualizations (as described in Figure 3). This group is also responsible to gather publicly available data to be used as a data base to be visualized.

Second, *Smart City Online Communities*, i.e., consumer-based focus groups as users of mobility services, provide for a ‘crowd-type’ community that might be driven by interest in customization of services, environment, resource efficiency etc. For this type of group, visualizations can support identifying regional coverage of offered services, or uncovered service demands. Additional data analysis techniques potentially allow quantifying citizen requests for better service coverage and stimulating innovation.

Third, the *Mobility Business Ecosystem Stakeholder Groups* include diverse sets of actors within the business ecosystem as such. The majority of entities can be included passively, i.e., without their knowledge or contribution to modeling, as information about their role in the ecosystem is either publicly accessible or because other organizations contribute information about their relationship to this actor during the modeling process.

Our learnings from the case study suggest that the VAS can serve all stakeholder groups by offering a tool to better understand their role in the ecosystem through reflecting on the visualizations and by providing reports and metrics to gain additional perspectives and a broader view of the ecosystem.

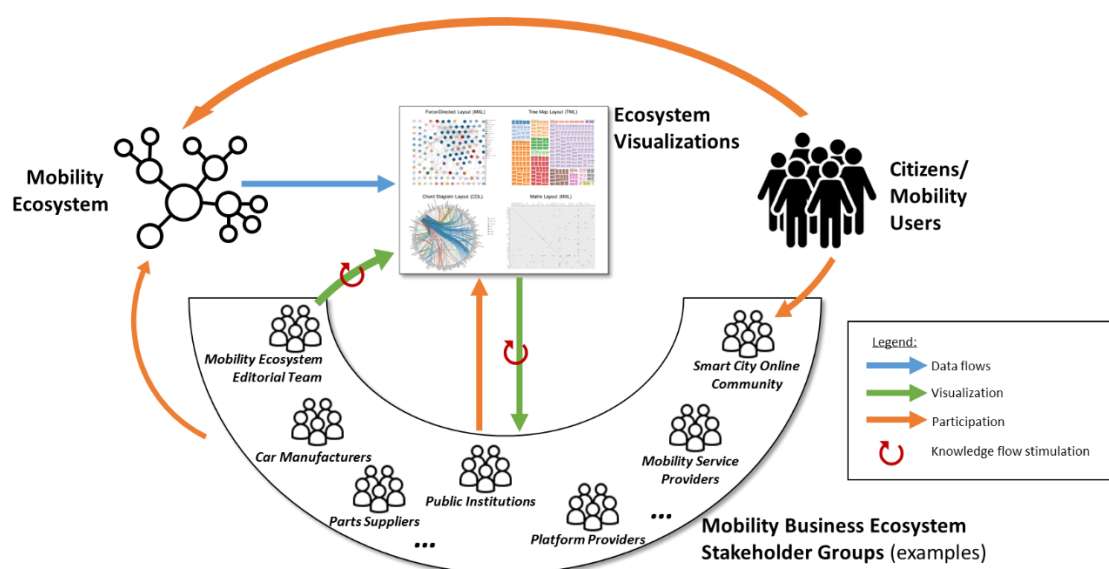


Figure 6. Visualizing to stimulate knowledge flows in smart city mobility ecosystems (adapted from [13]).

5.2. Conclusions

In this article, we report on findings from the development, implementation and prototypical deployment of a Visual Analytic System (VAS) in the case study context of a smart city initiative. The visualizations provided by the VAS were intended to support the mobility business ecosystem stakeholders by providing informative value, and by stimulating reflection on the ecosystem in order to increase understanding of the ecosystem and improve related policy and business initiatives. In our case study, we could validate the contributive nature of agile processes and involved roles to collaboratively manage and adapt the business ecosystem model. Data collection in order to create and populate ecosystem models is a critical issue, and we introduce three basic categories for identifying, assessing and selecting Internet Data Sources that are supposed to serve as a guideline for future modeling projects. We also detail our developed ecosystem data and view models that represent a first explication of categories for visualizing smart city mobility business ecosystems.

Our future research targets at the wider application of the presented approach to collaboratively model, visualize and reflect on ecosystems. If ecosystem visualizations are to provide an attractive value proposition for diverse sets of ecosystem stakeholders, for policy makers, and for ecosystems of different contexts and in different parts of the world—each facing individual challenges necessitating specific solutions—the process of collaboratively creating and populating models on basis of crowd-based approaches will need to be studied on a wider scale. We believe that particularly the issue of using visualizations to stimulate knowledge flows between policy makers, stakeholder groups, and citizens need to be studied carefully with respect to how sustainable business cases for shared models can be found. A core question in that will be to arrive at large-scale consensus about the governance of data, including for instance user-generated data about individual citizens' commutes collected by crowd-sensing technology; data originating from use and provision of mobility services; or data about business operations and strategies. We are confident that visualizations can contribute to formulate sustainable policies and business strategies for improving urban life and development, to come closer to putting the vision of the “smart” city into practice.

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