

Automated Generation of Web Resources for the Locative Web

Rui José(✉)

Algoritmi Research Centre, University of Minho, Braga, Portugal
rui@dsi.uminho.pt

Abstract. The concept of the locative web has been around for a while. We should expect the web principles of openness and uniform access to provide a solid alternative for developing locative systems, but the locative web has never succeeded. In this study, we extend the original concept of locative web with a conceptual framework to support the large-scale publication of locative web content by many independent publishers. To pursue this vision, we explore the concept of a locative resource as a small, data-centric web resource that represents the information and actions meaningful for a specific locative situation. These resources can be automatically generated in large numbers from datasets, and each can serve a very concrete situation. Our research aims to study the tools and processes that could support the convenient and cost-effective transformation of locative datasets owned by multiple independent entities into a global web of locative resources. As part of the experimental work, we developed a prototype implementation of a locative sites toolkit. We also developed four deployment case studies, in which we used that toolkit to generate locative resources from diverse types of datasets. The key contributions are a set of novel concepts for locative web systems and a set of guidelines for dealing with data heterogeneity and allow many independent entities, all of them with their particular datasets and publication goals, to conveniently publish their data as locative resources while promoting their convergence as part of a global locative web.

Keywords: locative web · data-centric · linked-data

1 Introduction

Locative media is a familiar presence in our lives nowadays. We have diverse systems that seek to explore the blending between the physical and the digital worlds. Location-based applications are now a given, allowing us to find our way in an unknown territory, make a more engaging visit to an art museum, or remember where we parked our car. Millions of users are constantly producing geo-tagged or place-based content by taking photos, following routes, publishing tweets, and making restaurant reviews.

© The Author(s), under exclusive license to Springer Nature Switzerland AG 2026
O. Gervasi et al. (Eds.): ICCSA 2025 Workshops, LNCS 15891, pp. 44–60, 2026.
https://doi.org/10.1007/978-3-031-97617-9_4

However, most of these services are delivered as custom mobile applications. Each of those applications packages the information, usage contexts and interactive features needed to offer a particular locative experience. This strong coupling between a mobile application and a specific locative situation allows the application to be designed to match precisely its target usage context. Ideally, this would offer the best possible user experience, but in reality, it becomes a fundamental limitation to a broader deployment of locative services.

The first problem is that embedding this association directly into the application design is not scalable for either service creators or users. For service creators, this custom development can be costly and limited budgets commonly result in low-quality applications that fail to meet user expectations or produce the intended engagement. For service users, an extensive application offer is also not the answer. Each application serves only a tiny fraction of potential usage situations. Any person would need to install endless applications and constantly switch between them to match the multiple, diverse, highly dynamic and often overlapping activities that compose daily life. Not only will no one ever be able to do that, but people rarely even become aware of applications created only for less frequent or unexpected situations. The consequences are high development costs and a small user base.

The second problem is how this development paradigm leads to extreme conceptual, technical, and administrative fragmentation, making it hard to create locative systems beyond a single management domain. Each application becomes a usage and data silo, and even if multiple applications serve the same physical space, they cannot combine their service value, as there are no easy paths for integration. This fragmentation is particularly harmful in urban contexts, where many independent information layers might be needed to serve diverse personal interests, immediate needs, or thematic perspectives. This fragmentation is a serious obstacle to convergence and generativity, two fundamental enablers for the disruptive nature of digital innovation [18].

These limitations have been highly detrimental to the open and widespread deployment of locative services. Even though we are witnessing a significant trend towards many new forms of locative data across public and private entities, there are no convenient and effective ways to deliver such data as part of genuinely locative experiences. We have many open data repositories, mapping systems, location-based APIs and web portals making locative data available on the web, but the value of this data is never truly realised until it is placed in those contexts where it would be more meaningful. We can thus conclude that many potentially valuable locative services are never created because of the high entry barrier associated with the custom mobile application paradigm. This represents a significant missed opportunity and a massive waste of potential value for data owners and for those who would benefit from those services.

1.1 The Locative Web

A fascinating aspect of web technology is how it can be appropriated for endless purposes. The basic principles of openness, scalability and uniform access [1]

have allowed the frontiers of web development to expand continuously through creativity and ingenuity more than by cutting-edge technologies. These basic principles should also provide an obvious and sound alternative for developing locative systems. However, the concept of a locative web [17] has never produced any meaningful impact. Locative services remain one of the few areas where web technologies have not yet been able to deliver the same level of openness and interoperability that has entirely reshaped other domains. Even though the potential for a locative web is everywhere, it also remains beyond reach.

In this study, we extend the original concept of locative web with a conceptual framework to support the large-scale deployment of locative web content by many independent publishers. We build on the vision that locative services should aspire to the same universality and openness principles of the web. To pursue this vision, we explore the concept of a locative resource as a small, data-centric, web-based resource that represents only the information and actions considered meaningful for a specific locative situation. The core idea is that these resources might be automatically generated from datasets so that they can be produced in large numbers, and each can serve a very concrete situation. These resources can then be linked through a variety of semantic connections. With this design, we can attain all common web capabilities while also supporting multiple situated information-finding practices.

This solution may represent a breakthrough for locative services. Firstly, it offers a low entry barrier for the creation of locative services, allowing any entity to conveniently publish its locative data and make it readily available for anyone to use in the proper contexts and for any purpose. Secondly, links between resources provide an open model for the interoperability between many heterogeneous and independent systems, bringing them together into a coherent whole composed of the autonomous and open contributions of many independent entities. Thirdly, a web representation of locative resources allows any system resource to be addressed in a unified way by any web browser. It also paves the way for a new generation of universal locative applications supporting interaction across any locative resource, anywhere, and for diverse and possibly unforeseen purposes.

1.2 Research Goals

Our research goal is to produce new knowledge about tools and processes to support the convenient and cost-effective transformation of locative datasets owned by multiple independent entities into a global web of locative resources. From a technical perspective, we will repurpose, as much as possible, the plethora of technologies, standards and best practices at the core of the success of the Web. The key challenge, however, is how to empower many independent entities with very different datasets and publication goals to freely create their own publication processes while promoting convergence between their independent operations. The key contributions of this work are a novel locative resource concept that connects the Web to concrete situational contexts, a locative site

toolkit designed to support the transformation of source data into collections of locative web resources, and a set of guidelines for dealing with data heterogeneity.

2 Related Work

Many cities have experimented with various technologies for locative services. Examples include mobile applications, augmented reality, digital twins or even common websites. Digital Twins [13] provide a joint digital model combining many layers of services. They are proposed as a data-centric platform for smart city practitioners to conduct simulations and demonstrate alternative urban development scenarios [8]. Likewise, 3D city models [2] are also becoming increasingly common and benefiting from 3D spatial data standards, such as CityGML [12] or BIM [15]. These systems may support a broad range of tasks beyond visualisation, but they are primarily meant for simulation, predictive maintenance and applications that require geometric models. OGC standards aim to guarantee interoperability and maximise the value of geospatial data. This allows OGC-compliant software, e.g. GeoCloud4SDI [16], to be interoperable and ready for adoption across multiple cities, but the focus is on providing complex geoprocessing capabilities [10]. They do not represent an alternative to the generic and widespread publication of locative services.

Web technologies can offer a powerful foundation for openness in geospatial efforts [11]. The Locative Web initiative [17] aimed to leverage web technologies as the content model while adding locative properties to link web resources to specific locations. However, simply embedding locative data into web pages does not support the integration of locative resources from many domains into a coherently locative web that people can easily discover, access and navigate for their own purposes. Openness in locative systems has also been addressed in the context of public display networks [6] as a model where the roles of display owners and content creators could be separated. Data Spaces [4] is a major initiative to promote the potential of the emerging data-driven economy. Their primary purpose is to create a context where multiple entities in a target domain may agree about which data they are willing to share under what conditions and for what purposes. Data spaces may become a significant source of domain-specific quality data for locative web resources, for example, in the areas of cultural heritage [14] and urban data [5].

The novelty in our work emerges from the unique combination of simple, tested and well-known web technologies and a data-driven content generation process that enables a systematic approach to the representation of locative web resources. This is unique in the way it can bring together the many layers of endless urban stakeholders into a coherent web of locative data and services. It is also unique in how it may offer a consistent interface to the digital features associated with any place, point, object, service, event or street in the city.

3 Conceptual Model

This section describes our initial efforts to conceptualize a novel locative web system. We introduce two key concepts that may help materialize web support for locative systems: locative resources and locative sites.

3.1 Locative Resources

The locative web resource is the core concept and the unifying abstraction in our vision for a locative web. A locative resource represents a small content unit associated with a physical or abstract context. As web resources, they are identifiable entities that can be accessed over the web via a URI (Uniform Resource Identifier). They represent a locative entity of a specific type, and they contain a structured data payload representing that entity. These resources are locative primarily because they contain contextual properties describing their target situation, e.g. a place name, a set of coordinates, an area served or some abstract usage context. Their content should correspond to the information and actions meaningful for that situation.

In line with the vision of a device-independent Web [3], locative resources should be ready to be delivered via many different web-connectable access mechanisms. Their primary representation is in the form of a linked data object [7] in json-ld. All resources share the same general structure, even though their data payload will be specific to each resource type. This structured representation is essential for broad interoperability and to facilitate agents' interpretation of locative resources. It is also the core data from which multiple other representations can be created for specific presentation channels, such as custom mobile applications, augmented reality or public displays.

The assumption is that these structured resources are generated through automated processes directly from data sources. This is essential for publishing them in large numbers and matching each with a very specific usage micro-context. To ensure universal access by humans, locative resources should also have an HTML representation. The generation of the web representation should also be automated and entirely based on the respective json-ld representation. This model shields the web generation process from any dependencies on source data, publication context or navigation structures other than settings related explicitly to HTML content, such as web presentation frameworks or visual presentation settings.

The structure of a json-ld representation of a locative resource is represented in Fig. 1. It comprises five major sections: Resource Header, Master Data Entity, Related Data Entities, Relationships and Imported Elements.

Resource Header. The Resource Header section provides a set of generic properties for describing any locative resource. This common schema is key in the unified model for locative resources. Clients can always expect to find subsets of these properties, and they will be able to interpret them across any type of

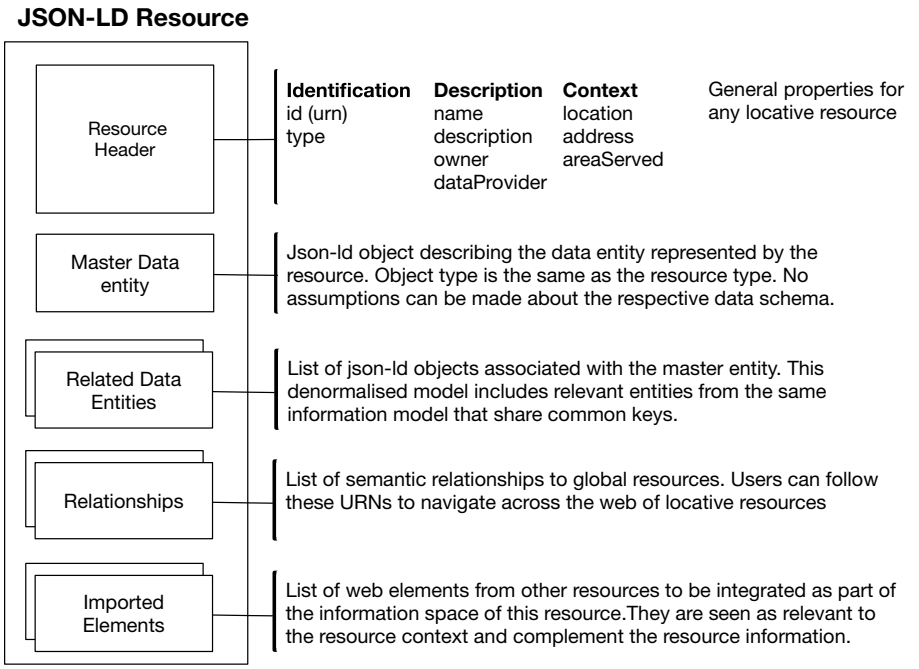

Fig. 1. The structure of a locative resource.

locative resource, regardless of its data payload. This guarantees interoperability, universality of resource access and navigability across the entire web of locative resources. Some of these properties, e.g. the domain name, will be based on attributes from the publication context. Others, e.g., the title, will be based on attributes from the data payload of the resource, particularly in the master entity.

The id attribute provides a unique ID for resource identification. These identifiers for locative resources follow NGSI-LD entity naming rules, with some adjustments to make them more aligned with the requirements of a federated system, where URNs need to be globally unique, resolvable, and interoperable across different organizations. Further generic attributes include the resource type, name, title, description, data provider, and other metadata properties that help to provide a multidimensional resource description.

Another set of Resource Header properties supports the association between the resource and specific locative situations. We consider diverse types of situational properties, such as geographic coordinates, address, place IDs, a symbolic location name, a served area, an activity type, or any other property that may help to characterize the context to which the respective content is associated. As shown by previous locative web efforts [17], simply adding coordinates to web resources is not enough to create locative experiences. However, this is still an essential element for linking resources to contexts in a way that is valuable for

both Humans and machines. These properties can be globally unique identifiers, but they can also be local references within a specific domain. This allows the system to repurpose many types of situated context hints, such as a street name, an office number or an image of an artwork.

Master Data Entity. The Master Data Entity section is the main data payload in a locative resource. It contains a linked-data object with the core data associated with the entity represented by the locative resource. If the locative resource represents a bus stop, this entity might be a GtfsStop object with the key information about the bus stop itself. While any schema can be used in this master data entity, ideally, it should be based on standard data models many third parties can interpret.

Related Data Entities. The Related Data Entities section contains complementary data related to the entity represented by the master data entity. For example, a resource representing a bus stop should include information about the stop itself (id, name, location). However, it should also include information about which bus routes stop there and when. This information is not directly about the stop itself but will be critically relevant for most people at that stop.

This resource section addresses a core challenge associated with the mapping between the information model of the source data and the information model represented by locative resources. Locative resources are not abstract data entities within a more extensive data model, at least not in the traditional sense of an entity-relationships model. Their purpose is to serve as a focal point for all the relevant information and services about a specified context and offer Human users a valuable locative experience. Therefore, each locative resource should be conceived as an independent physical or abstract entity that is meaningful for users in a given situation and encapsulates all the relevant data from that perspective.

Mapping these two perspectives requires a suitable balance between what should be provided at a single resource and what should be available by switching to another resource. Interpreting information in the proper context can provide locative meaning to that information, which is a key goal of this model. However, too many small resources associated with very small contexts may lead to excessive context changes, hindering user experience. Information should thus be provided in contexts that are relevant and meaningful to users, and it should include enough related information to support the most common needs and avoid an excessive number of context changes.

To serve this purpose, locative resources need to support some level of denormalization that combines the representation of a master or parent object with the representation of key-related entities as nested data. This may result in data duplication across locative resources, but it helps them serve their role as aggregating contexts for information related to a given situation.

Relationships. The Relationships section represents connections to other related resources. Like on the web, links represent interactive jumps to a different resource with a different context based on the semantics of a relationship between both resources. These connections form the edges of a global locative data graph, where locative resources are the nodes. These relationships play an important role in defining the situated context of resources. We can expect many of these relationships, especially those within a single information model, to be primarily derived from data relationships. However, many others, especially those between different data domains, can be expected to be primarily based on the proximity of their situational contexts. These relationships provide navigation possibilities that help people reach the most relevant resource in a given situation, even if they start from another situationally proximate resource, possibly from another information domain. This ability to move between related contexts until reaching the most suitable one is essential because situated information-seeking strategies can be much more meaningful when they include the users' ability to interpret their current situation. They can navigate a situated information space and "tune in" to any content relevant to the current situation without relying on complex personalisation mechanisms. Therefore, these relationships can also be seen as another element, in addition to contextual properties, that can help establish the situational relevance of locative resources. They offer a more flexible and crowdsourced model for extending the semantics of their situational relevance.

Imported Elements. The Imported Elements section supports data sharing between resources. It enables a presentation unit from one resource to be included as a presentation unit at another resource. For example, elements from nearby bus stops, showing the next departures at each stop, might be included in a campus resource describing travel alternatives from the Campus to the City Centre. This is a fundamental flexibility mechanism of the system, enabling data from one resource to be included as relevant information within the context of many other resources. To be more effective, this is something that should occur primarily in the web representation of resources. This way, the mapping between a particular data entity and a web component that can present it is a problem that only needs to be addressed once, at the source resource where the element was originally published. Importing elements from other resources does not necessarily establish any relationship between those resources. It is just about sharing content across many contexts where it might be relevant.

3.2 Locative Sites

We introduce the concept of a locative site as a publication context for locative resources in a single information model. Resources in the same locative site will share a common domain name and will be part of the same administrative domain managed by a single publisher entity. One can imagine a locative site corresponding to what is normally expected as the scope of a simple themed mobile application for an event, a museum, an urban tour or an urban resource directory.

A locative site consumes several data sources to generate and publish locative resources based on that data. We envision that publishers may choose diverse tools and practices to publish their locative sites, mainly depending on the nature of their source data. These could range from interactively editing their data on a dedicated platform to importing and transforming large datasets. Regardless of these many possible tools, locative sites are always expected to be generated by automated processes. This automation empowers publishers to create rich locative experiences directly from their data. It is also the enabler for some of the core properties of the concept, such as: the ability to publish large numbers of small and unique resources, each targeting only a specific locative context; promoting a common structure across all resources; and generating multiple coherent representations of the same resource, e.g. JSON or HTML.

Unlike common websites, which are mainly conceived from top to bottom, locative sites are mainly about the specific data elements they publish and not so much about their aggregate perspective or navigation structures. The publication of a locative site is structured around resource bundles. Each bundle constitutes a publication unit within that locative site and supports the transformation and publication of a specific type of resource from a specific data source. All the resources in the same bundle will thus represent the same entity type and be based on the same data model, with each resource corresponding to an item in the source dataset. Examples of resource bundles may include the list of bus stops of a bus operator, the list of exhibition rooms in a museum or the list of bike racks in a city.

Locative sites can be published independently; therefore, each site may have its own data model. Still, resources can have any type and number of connections to other resources outside the respective locative site. This allows locative sites published by many autonomous entities to converge into a single and continuous locative web without enforcing any centralized solution.

4 Experimental Work

To assess the potential of this novel locative web approach and uncover possible limitations, we conducted an experimental work that combined the implementation of a locative sites toolkit, the development of four case studies involving diverse locative datasets and the progressive optimization of a data transformation workflow to support the publication of the respective locative resources.

4.1 Locative Sites Toolkit

The concept of locative resources does not involve any assumptions about how they are published. Like on the web, we envision many publication practices, from individual interactive publications to automated large-scale generation processes. Our initial implementation of a tool for generating locative sites from locative datasets was mainly driven by the need to experiment with publication processes and allow tools and practices to evolve side-by-side. As part of

our effort to identify and characterize publication tools for locative resources, we have implemented a development library and a set of data models and templates to support the efficient and reliable transformation of source data into locative websites representing specific information domains. This development was made progressively and alongside the development of the four case studies. The diverse requirements emerging from those four studies have been instrumental in the toolkit's design, and the toolkit was at the core of all four case studies. At a conceptual level, this toolkit helps to accomplish the following tasks:

- Publication of a locative web domain comprising various interconnected collections of data entities and their respective web representations
- Methods to streamline the transformation of various data sources into json-ld while validating and adjusting data according to standard data models.
- A common web publication model that offers a familiar interface across resources and supports core navigation features between resources.
- The ability to generate web representations for the various types of data models present in the resource data.
- A set of relationship management techniques to support the flexible integration of various types of resources, possibly published by many independent stakeholders

4.2 Case Studies

To improve the validity of the process and broaden the range of requirements, we selected a diverse set of case studies, specifically the four case studies described in Table 1.

Table 1. Summary of the four case studies

Case Study	Description	Source Data
City Statues	Inventory of all urban statues	Spreadsheets + Images
Bus Information	GTFS data about local bus system	GTFS data
Christmas Fair	Stages, events and timetables	WebSite + PDF
Department	Department offices and their usage	Spreadsheets + Images

These case studies are diverse regarding their application domains, the nature of their source data or the complexity of their information models. Together, they pose diverse challenges and appeal to different sets of features. They are all real use cases for which other alternatives to provide the same information have already been tried, either as mobile applications, websites or paper leaflets. This confirms the relevance of the case studies and provides a strong background for comparing approaches.

The City Statues case study provides information about the statues in the city of Braga. This data was only being used internally by the Municipality services as an inventory of local patrimony. The service comprises locative resources describing each of the statues, including information about the author, the type of work, a description, the location and photos. The source data is structured as spreadsheets, along with image files of the statues. The Bus Information case study was entirely based on standard GTFS data from the local operator. This case study is more complex regarding the information model, with various types of data entities, but it leverages the benefits of a standard data model. The Christmas Fair case study is the program for Christmas events in Braga. This data was available as a PDF document and also as a website. This is the most challenging case regarding the information format because there are many potential data entities and many alternative ways to design the information model. The Department case study involves information about our University Department, combining different layers of information related to rooms, people, events and activities.

4.3 Development Workflow

The development of the four case studies involved starting with basic, custom workflows and then progressively introducing new abstractions and convergence mechanisms that could generalize the custom strategies emerging from each workflow. The goal was to identify the most relevant abstractions and practices for the large-scale semi-automated generation of locative web resources from datasets. Figure 2 represents the generic structure of the process, which comprises three main steps: data modelling, generation of the json-ld representation of each locative resource and generation of its web representation.

Data Modeling. The initial data modelling step is the identification of the entities represented by the data, with their properties and relationships. At this stage, this is mostly a logical data model, which is expected to be detailed in terms of specific attributes and relationships but makes no assumptions about concrete types or representations. The source data may then undergo multiple data transformation processes before it can be used as input to generate locative sites. These transformations may involve procedures to adjust, combine, merge, estimate or complete the source data. The most common examples may include the combination of data from multiple datasets, the adjustment of data field names and values, the generation of metadata, the categorization of data items and the association of external media, such as images. This is a common ETL (Extract, Transform, Load) process for which data processing tools already exist. The problem is that, without concrete expectations about the source data, there is not much that can be generalized. However, we can design the process to mitigate the complexity associated with heterogeneous data sources and promote convergence mechanisms. Our first convergence mechanism was to define the output of this process as a list of JSON objects, all with the same data schema and

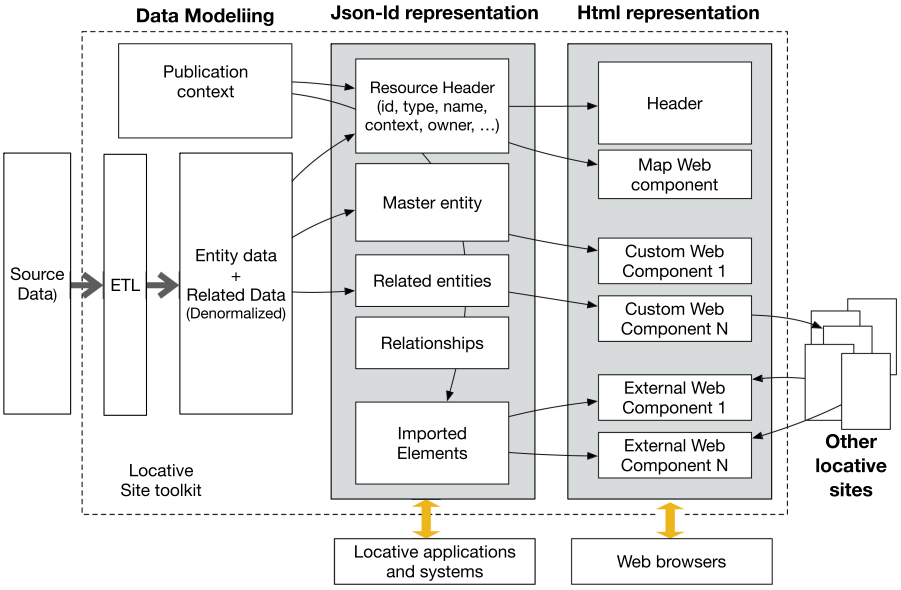

Fig. 2. Workflow for resource generation.

each corresponding to the data of one locative resource. This assumption isolates subsequent process phases from the inherent complexity associated with highly heterogeneous data sources. The second convergence mechanism uses data models to define how data is organized, stored, and managed. Data models provide a fundamental interoperability mechanism to promote convergence among diverse data sources, content types and presentation alternatives. More specifically, they should play a key role in the following features:

- Validation of data sources or data produced during transformation and export processes.
- Specification of the structure of locative resources in the core json-ld representation.
- Defining the types of entities represented by locative resources.
- Associating specific HTML representations with specific types of resources, thus promoting the reusability of development components.
- Automatic generation of UI interfaces for locative resources and services

Considering the key role that interoperability plays in these systems, locative resources should be, as much as possible, based on standard data models that can be interpreted unambiguously by any third party. In our implementation, we mainly used data models based on the NGSI-LD specifications [9].

Json-ld Representations. This step is where the locative resources are generated and published as JSON-LD objects. This publication occurs as part of

locative sites that represent a common publication domain by a specific publisher.

The generation process involves going through each of the data entities in the source data and combining its data with the general bundle and locative site properties to produce the json-ld representation of that resource. An important part of this mapping is the transformation of some of the specific data fields in the master data entity into generic properties of the resource header. Another is deciding which Related Data Entities to include in the locative resource. This decision should be linked with some level of anticipation about the nature of the data that should be presented to users in the web representation. The resource generation process also includes the integration of relationships within and outside the locative site being generated.

From the perspective of the publication of locative resources, it is relevant to distinguish between connections within a single locative site scope and those that span across the global locative web and involve multiple locative sites managed by autonomous entities. In the former case, there is complete knowledge and control over the data entities involved. In the latter case, these relationships must be explicitly defined as part of the publication specifications. The same is true for Imported Elements, which also need to be defined explicitly based on some interpretation of relevance.

Web Representation. In our toolkit, the json-ld representation is generated first, and the web representation is generated afterwards and is entirely based on the json-ld data. There are two main challenges involved.

The first is to transform the resource data into a unified web interface for any locative resource. Web interfaces provide a simple but universal channel to deliver the value of locative information. They should identify the resource, display data elements that can represent the resource data and leverage relationships to offer navigability opportunities to other resources. Depending on their semantics, some relationships can be presented as navigation menus. Others might be presented as data elements with a link for more advanced interactions with the target resource. In this study, we have not made significant advances in the design of this generic interface.

The second challenge is to create web representations for data schemas that can be very diverse. Regarding this challenge, we explored a solution based on web components. This involves creating the web components according to specific guidelines and then registering them to be associated with a specific data schema. This association only means that the web component was conceived for that specific data schema and does not imply any assumptions about what will be presented. The expectation is that for a single data schema, many different visualisations may be created to embrace creativity and present very diverse perspectives about that data. In our implementation, we explored this approach and developed several web components for the schemas in our case studies.

5 Discussion

The implementation of the locative sites toolkit and the development of the four case studies described in the previous section were instrumental in assessing the various dimensions involved in transforming data into locative resources. In particular, they have provided us with relevant findings about the challenges raised by data heterogeneity and different strategies for dealing with it. Each case study faced its own small obstacles, but the real challenge was their diversity and the ability of the system to handle those heterogeneous datasets and publication goals. Addressing this challenge involves a delicate balance between openness and convergence. On the one hand, we need openness to embrace the inherent heterogeneity stemming from a vast diversity of endless data sources managed by multiple autonomous entities. On the other hand, we need convergence to ensure that the output of all those transformations is consistent and ready to integrate a global web of locative resources. When developing these case studies, we identified four general guidelines that may help to manage this trade-off.

Avoid Heterogeneity. The most impactful way to address heterogeneity is to avoid the problem altogether. We cannot impose our own standards, but we can acknowledge that many de facto standards are widely used across many domains. They are well-tested, they have formal specifications, and some of them can be very relevant to society in general. For example, the General Transit Feed Specification (GTFS) is used by transit agencies across the world to publish up-to-date transit information. Because of GTFS, we could easily reproduce our Bus Information case study in many cities worldwide. Recent trends towards dataspaces might help many more domain-specific standards to emerge as clear winners in those domains.

Divide the Problem. The second strategy is to decompose the resource generation process into key functional scopes, each addressing only one specific part of the problem and its input assumptions. We did this when we defined the input for generating locative resources as a list of JSON objects of the same schema. We can extract two significant benefits by breaking the larger problem into smaller ones. The first is that well-defined boundaries between different parts of the problem help to limit the propagation of the complexities caused by heterogeneity. The other is that having smaller and simpler parts will significantly help find similarities between independent transformation processes. This should promote the emergence of common abstractions and tools that may hinder heterogeneity within that particular context.

Absorb Heterogeneity. Assuming we will always have to deal with heterogeneity, the following guideline is to absorb the impacts of heterogeneity. We have used three primary techniques that fit this concept: smaller schemas, avoidance of type proliferation and repurposing custom data fields as generic resource properties. Smaller schemas are a valuable practice because a larger schema is never

a perfect match when we try to repurpose it across different domains or datasets in the same domain. Smaller schemas are much more reusable than larger ones because they can be recombined to form larger concepts. For example, contextual properties in our locative resources are small and widely used schemas to represent addresses, locations, service areas or places. Even if some parts of a locative resource are not known to a client, these smaller and highly recognisable schemas will ensure that key parts of the resource can be interpreted appropriately. Another technique is to avoid type proliferation, i.e. the excessive creation of distinct data types to represent variations of similar entities. This proliferation can lead to unnecessary complexity, maintenance challenges, and reduced code readability. In our model, resource types describe the type of entity represented by the resource but do not mandate any data schemas. By separating resource types from rigid expectations about the data in those resources, we avoid the traps of type explosion. Finally, we also designed the transformation process in a way that many specific properties of the master data representing the resource are mapped into generic properties of the resource header, making sure that even if a particular client cannot interpret the master data, the fundamental properties of that resource will still be able to provide key information about that resource. This creates alternative, partially redundant representations of the same data on the same resource. However, it introduces another layer of flexibility for addressing distinct usage contexts based on that data.

Drive Convergence. The final insight is about promoting convergence. Developing our four case studies involved many micro-design decisions, most of which were not particularly relevant to the outcome of any process. However, when we consider the development of multiple locative sites, it becomes evident that many similar problems are being addressed separately as site-specific problems. Consequently, we end up with many separate, slightly different, incompatible solutions to similar problems. Most of those solutions will be perfectly reasonable, and it will even be hard to claim that any of them might be better or worse. The problem, however, is how everyone will be repeating the same effort over and over again. Still, we do not wish to hinder innovation. On the contrary, we would like a thriving community where new solutions may continuously emerge to complement or replace previous ones. From this perspective, what is essential is the ability to drive convergence by progressively promoting shared reusable elements. This is a form of nudging developers to convergence by giving them the alternative to reuse what has already been developed instead of spending their effort creating another solution to a solved problem. Schemas can also become a key driver for the convergence and reuse of components. On the input side, they can allow data transformation processes to be replicated across many data sources. They should also enable simple, guided, assisted processes for locative content generation. On the output side, they can support the development of web components that present specific data elements anywhere such data may exist.

6 Conclusions and Future Work

This paper presents a novel locative resource concept that may help create a new generation of web-based locative services. We describe the concept and early implementation of a locative site toolkit designed to support the transformation of source data into locative web resources. A key challenge in this approach is generalising those data processing activities. Based on the results of four case studies, we identified four general guidelines that may help mitigate the consequences of heterogeneity and contribute to the viability of more generic locative resource generation procedures. In future work, we aim to explore how artificial intelligence techniques may help to understand the data entities composing any information model and assist with the mapping to specific types of locative resources.

Acknowledgments. We acknowledge the contribution of Braga Municipality in providing the statues data used in this study.

Disclosure of Interests. The authors have no competing interests to declare that are relevant to the content of this article.

References

1. Berners-lee, B.T.: Long live the web. Sci. Am. 80–85 (2010)
2. Biljecki, F., Stoter, J., Ledoux, H., Zlatanova, S., Çöltekin, A.: Applications of 3d city models: state of the art review. ISPRS Int. J. Geo Inf. **4**, 2842–2889 (2015). https://doi.org/10.3390/ijgi4042842
3. Butler, M., Giannetti, F., Gimson, R., Wiley, T.: Device independence and the web. IEEE Internet Comput. **6** (2002). https://doi.org/10.1109/MIC.2002.1036042
4. Commission, E.: Commission staff working document - on common European data spaces (2022)
5. Cuno, S., Bruns, L., Tcholtchev, N., Lämmel, P., Schieferdecker, I.: Data governance and sovereignty in urban data spaces based on standardized ICT reference architectures. Data **4** (2019). https://doi.org/10.3390/data4010016
6. Davies, N., Langheinrich, M., Jose, R., Schmidt, A.: Open display networks: a communications medium for the 21st century. Computer **45**, 58–64 (3 2012). https://doi.org/10.1109/MC.2012.114
7. Heath, T., Bizer, C.: Linked data: evolving the web into a global data space. Synth. Lect. Semant. Web: Theory Technol. **1**, 1–121 (2011). https://doi.org/10.2200/S00334ED1V01Y201102WBE001
8. Hämäläinen, M.: Urban development with dynamic digital twins in Helsinki city. IET Smart Cities **3**, 201–210 (2021). https://doi.org/10.1049/smc2.12015
9. (ISG), C.I.M.C.E.I.S.G.: Context information management (CIM); OpenAPI specification for ngsi-ld api (2024)
10. Kiehle, C., Greve, K., Heier, C.: Requirements for next generation spatial data infrastructures-standardized web based geoprocessing and web service orchestration. Trans. GIS **11** (2007). https://doi.org/10.1111/j.1467-9671.2007.01076.x
11. Kolas, D., Dean, M., Hebeler, J.: Geospatial semantic web: architecture of ontologies. In: IEEE Aerospace Conference Proceedings 2006 (2006). https://doi.org/10.1109/aero.2006.1656068

12. Kutzner, T., Chaturvedi, K., Kolbe, T.H.: CityGML 3.0: new functions open up new applications. PFG – J. Photogram. Remote Sens. Geoinf. Sci. **88**(1), 43–61 (2020). https://doi.org/10.1007/s41064-020-00095-z
13. Lehtola, V.V., et al.: Digital twin of a city: review of technology serving city needs. Int. J. Appl. Earth Obs. Geoinf. **114**, 102915 (2022). https://doi.org/10.1016/j.jag.2022.102915
14. Niccolucci, F., Felicetti, A., Hermon, S.: Populating the data space for cultural heritage with heritage digital twins. Data **7** (2022). https://doi.org/10.3390/data7080105
15. Oulidi, H.J., Hajji, R.: Open BIM Standards (2021). https://doi.org/10.1002/9781119885474.ch4
16. Tripathi, A.K., Agrawal, S., Gupta, R.D.: Geocloud4sdi: a cloud enabled open framework for development of spatial data infrastructure at city level. Earth Sci. Inform. **16** (2023). https://doi.org/10.1007/s12145-022-00893-6
17. Wilde, E., Kofahl, M.: The locative web. In: Proceedings of the First International Workshop on Location and the Web - LOCWEB '08, vol. 300, pp. 1–8 (2008). https://doi.org/10.1016/S1071-5819(02)00127-1
18. Yoo, Y., Boland, R.J., Lyytinen, K., Majchrzak, A.: Organizing for innovation in the digitized world. Organ. Sci. **23**, 1398–1408 (2012). https://doi.org/10.1287/orsc.1120.0771