Infrastructure Management in Swiss Municipalities - Development of a Modern, Spatially Enabled Management Cockpit

Simon HOFER, Christoph SCHALLER, Patrick HARING and Jürg H. LÜTHY, Switzerland

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SUMMARY

Swiss municipalities own about half of the existing public infrastructure in the country, worth over 460 billion CHF. They face enormous challenges, not only in operating and maintaining the infrastructure, but also in planning replacements and future investments. Major parts of the entire infrastructure are nearing the end of their life cycle and will have to be replaced over the next decades. In order to meet these challenges, municipalities need suitable processes based on tailored infrastructure management strategies. Typical management instruments support these processes and help to plan, coordinate and make decisions based on key facts and figures.

An interdisciplinary team from university, industry and municipalities developed a specialized instrument supporting an efficient and coordinated management of municipal infrastructure based on the combination of spatial and textual data. Key features of the cockpit include planning of long-term investment, coordinating the planned actions and visualizing relevant management information for both administrative and executive needs in a dashboard.

The cockpit employs small, specialized apps (e.g. a map client or a project planning component) that can be combined into more complex applications. The apps utilize a number of common base components that implement much of the core functionality of the architecture. A data abstraction layer with pluggable data adapters allows the declarative definition and combination of data from different sources as well as the creation and management of references between objects from different sources using services.

The modern and highly-flexible architecture does not require a change of responsibilities or of the data maintenance processes. The cockpit supports the municipalities in developing their infrastructure strategy and continuously monitoring the implementation progress. In this paper the core components of this service-oriented architecture are described.

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1. INTRODUCTION

Swiss municipalities own about half of the existing public infrastructure for transportation, water and energy supply, waste water disposal, worth over 460 billion CHF (Schalcher et. al. 2011). A typical Swiss municipality counts around 1300 inhabitants and the communal staff is less than 5 employees. Municipalities face enormous challenges, also in operating and maintaining the infrastructure. Major parts of the entire infrastructure are nearing the end of their life cycle and will have to be replaced over the next decades. The problems will intensify in future with the workload for planning replacements and future investments.

Fundamental problems for the municipalities are not only the limited staff but also the difficulty finding appropriate council members in the militia system (i.e. citizens take on public office which they perform alongside their normal jobs). Consequently, in many municipalities core tasks in the infrastructure sector are outsourced to privately owned companies. The 4-year legislation period of the council conflicts with the long life cycles of infrastructure components. The divided responsibilities between council, local staff and external engineer and lack of knowledge on the part of decision makers hinder an efficient and effective infrastructure management.

Last but not least it must be admitted that, although in general cadastral data for the transportation, supply and waste water disposal infrastructure haven been built up in a digital format, the available information is often not suitable for infrastructure management. Besides the utility cadastres most other datasets are a collection of unstructured information with missing common keys leading to a big effort for data maintenance. Inconsistencies between the data sets are widespread. Depending on the ability and capacity for manual data fusion decisions may be taken based on an incomplete or inaccurate information base.

Overall there is an increased demand for improving the entire infrastructure management in order to maintain the security of supply, to optimize the planning of investments with respect to costs and financial constraints (how much can be invested for the renewal per year) and, therefore, also smoothing the peak of investments and eventually to change from a reacting to an actively acting party. In order to meet these challenges, municipalities need suitable processes based on an infrastructure management strategy and instruments supporting it.

1.1 InfraGem

In a project co-financed by the Federal Commission for Technology and Innovation (CTI) an interdisciplinary team from university, industrial partners and municipalities (as pilot project partners) developed the specialized instrument *InfraGem* (**Infra**structure management in **Gem**einden/municipalities). The goal of InfraGem is the provision of instruments supporting the efficient and coordinated management of infrastructures and helping to plan, coordinate and make decisions based on key facts and figures. The instrument provides also a cockpit where all relevant spatial and textual data from the various data sources is assembled.

1.2 Related work

The project closely linked to a project of the Swiss Association of Municipalities and the Swiss Association of Cities in which an infrastructure management handbook for municipalities (Kommunale Infrastruktur, 2014) was developed. The management model and guidance from the handbook are incorporated into the development of the management instrument. The project also builds upon the results of prior projects and aims to integrate their results in the new management instrument. The ICT-Based Management Institute of Bern University of Applied Sciences has been doing research on management cockpits for public management for several years. In a prior CTI funded project a management cockpit for small and middle municipalities was developed (Neuroni et. al. 2009). This initial version of the cockpit had a more general focus on strategic management in municipalities and its support through IT based instruments (Mares et. al. 2010).

The system architecture builds upon the framework of GeoApps, an integration platform for a spatially enabled society (Lüthy, 2014). The development of GeoApps has been initiated to address the growing demand for flexible data use in a net-centric information environment. Whilst many digital data sets are nowadays available, the linking and integration of data sets describing similar real-world phenomena is typically specifically implemented. GeoApps in contrast provides a rule based combination of spatial and textual data, i.e. a generic platform for data integration. The data sources are requested ad-hoc using web-services, evaluated, combined and finally presented to the user in different kind of portrayals (maps, diagrams, pivot tables or simple lists). More data sources which support a service-oriented architecture may be added by simply providing an adapter on the GeoApps Server part.

2. SOLUTION APPROACH

2.1 Infrastructure Lifecycle

The solution builds upon a lifecycle process as elaborated by the Swiss Association of Municipalities and the Swiss Association of Cities in their handbook (Kommunale Infrastruktur, 2014). The following figure shows how the strategy level and the operation level are linked together. The lifecycle further illustrates the continuity of the waste-water infrastructure management.

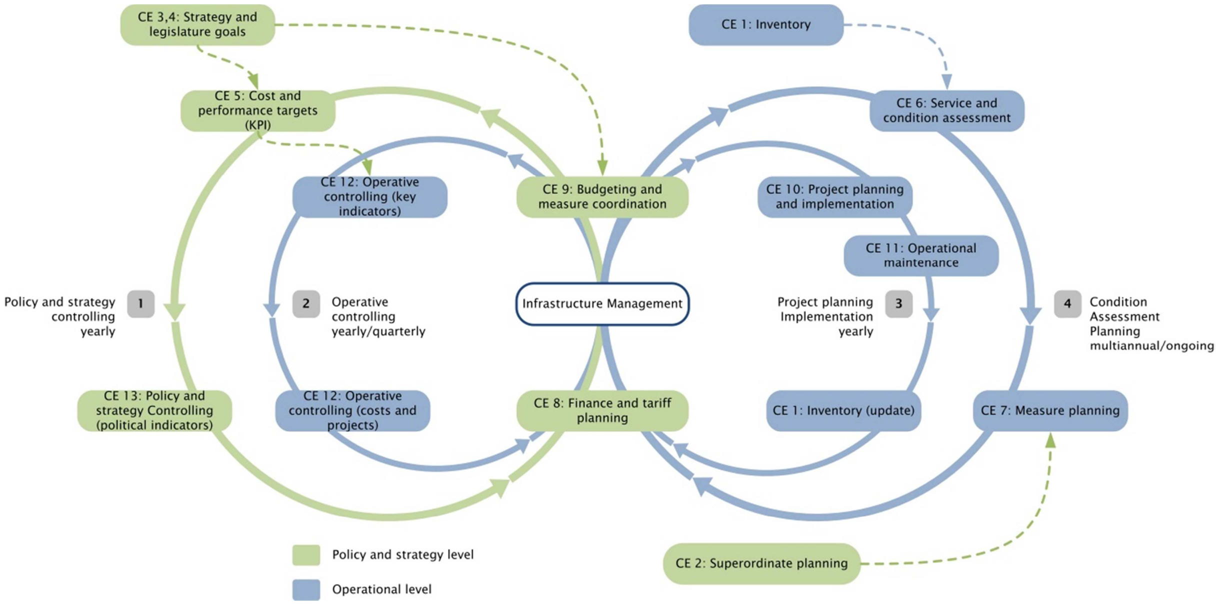

Fig. 1: Infrastructure Lifecycle according to (Kommunale Infrastruktur 2014)

2.2 Key features

Key features of the cockpit from a user perspective include:

- Supporting the elaboration and implementation of an infrastructure management strategy and suitable management processes;
- Providing management instruments to support these processes;
- Providing key performance indicators (indexed replacement values, aggregated data by year, condition) in order to help to plan, coordinate and make decisions based on key facts and figures;
- planning of long-term infrastructure investments;
- planning of improvements, replacement and renewal including cost estimates;
- coordinating the planned actions across infrastructures;
- fiscal-planning and long-term financial planning;
- visualizing relevant information for both administrative and executive needs (dashboard) and
- reporting.

The aim of the cockpit is, therefore, providing the responsible persons at the right time the data relevant for the respective questions from updated data sources in the adequate granularity and depiction.

2.3 On the benefit of the integration of spatial for decision support

Many decisions have either an explicit or implicit spatial component. Infrastructure management is a good example for the former case while encouraging the influx of young families is an example for the latter since in turn it will influence things like construction activities, demographics within quarters or the number of students in the vicinity of a school. In both cases the inclusion of tools like GIS benefits the decision making process. By overlaying the spatially related data from different sources on maps makes information accessible in an intuitive manner. By superimposing the condition of sewer infrastructures on a heat map for example hotspots with need for replacement can be identified easily. Within infrastructure management the spatial overlay of measures for different infrastructures helps to identify synergies. For instance if a road has to be reconstructed it may be sensible to also replace the underlying sewer and water infrastructure even if it has not quite reached the end of its lifetime. By consequently coordinating and planning such projects, the number of obstructions through construction activities can be reduced which also relieves the local economy and citizens. Furthermore the overall costs for infrastructure construction and the frequency of construction activities in one area can be reduced. The cockpit therefore provides functions for such analysis and the coordination of infrastructure measures and projects. Whilst the spatial information is useful for determining relationships many information required for the infrastructure management are kept in different information systems like financial aspects, asset management or maintenance. For a holistic view on the infrastructure the various data sources must be combined. The capability of integrating spatial and textual data is one of the key requirements for a spatially enabled society (Kaufmann et.al. 2012).

Figure 2 shows a schematic overview of the cockpit and parts of the surrounding architecture.

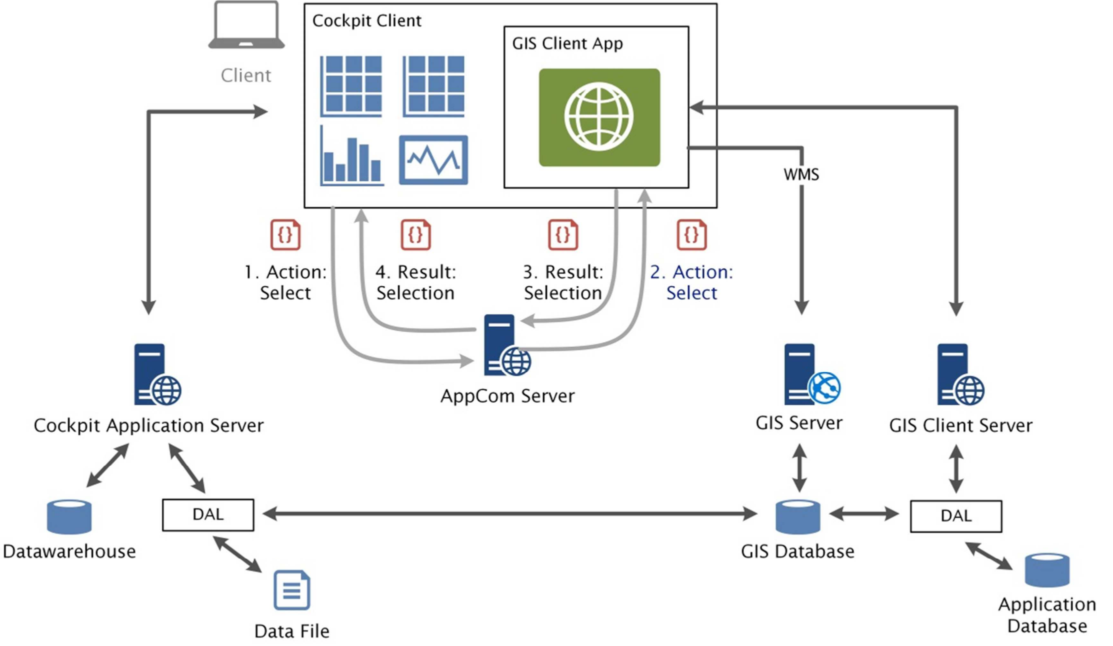

Fig. 2: InfraGem Architecture Overview

At the centre of the figure is an example view of the web based cockpit that integrates textual data from different sources and combines it with spatial information thus providing holistic decision support to the user. Maps are integrated into the cockpit by embedding a specialised GIS client app. To enable the integration of such apps a generic communication service called AppCom is used. Data from several existing sources is integrated by the cockpit as well as the GIS client leveraging the service-oriented architecture and the Data Abstraction Layer (DAL) developed in the project. Some of the most important technical requirements and challenges within this environment will be discussed in the following sections.

3. CHALLENGES

3.1 Application Communication

3.1.1 Determining factors for inter app communication

The app concept necessitated a standardised and generic mechanism that allows for the integration of the independent apps into arbitrary applications. Several factors determine the design of this mechanism. Apps are independent web applications and generally use RESTful web services for client/server communication. Therefore only the browser as the remote application knows the exact state of the user session. Thus the communication between the apps has to be initiated from the browser that runs the app. The project aims to leverage modern communication features of web browsers (e.g. Web Sockets or cross-document messaging) to implement the inter-application communication in a fast way. However, older communication technologies and mechanisms (e.g. long-polling using http requests) have to be supported as a fall-back option. Furthermore it has to be possible to integrate the communication mechanism into fat-clients that want to make use of apps. Last but not least the integration into SharePoint has to be possible since it serves as basis for the cockpit.

3.1.2 AppCom: a web service for inter-application communication

A communication service called AppCom has been implemented to address these requirements. The technical foundation of AppCom is the ASP.NET based SignalR library that is intended for real-time bi-directional communication between client and server. SignalR is based on Web Sockets and provides fall back options for older browsers by default. With both JavaScript and .Net client libraries it also allows for the integration of AppCom into web apps (including SharePoint) as well as fat-clients. On top of the SignalR infrastructure AppCom provides services for inter application communication. The AppCom server manages sessions wherein one client can add other clients to the session. Clients can announce their functions that then can be called by other clients in the session. It is also possible to get a list of clients within a session from the AppCom server. Furthermore clients can trigger and listen to events in order to be able to react to or to influence other clients. It has to be noted that the clients within a session don’t necessarily have to run within the same browser or even on the same device. The communication between apps on different devices is also possible (e.g. running a cockpit app on one computer and a GIS client on a separate tablet). AppCom can be regarded as an infrastructure for service orchestration.

3.1.3 A usage example and first experiences with AppCom

Illustrating this communication following the example depicted in Figure 2: the cockpit application upon start-up first opens a connection to the AppCom server creating a new session. Then it announces its own functions to the server. After that the cockpit client can communicate with other apps in the same session. When a view with a map is opened, the cockpit client will start a new instance of the GIS client app and provide this app with the information to join the existing session. Once the GIS client has joined the session and announced its own function, they both apps can interact. For example the cockpit could initiate a selection on the map by sending the according message to the AppCom server (1) which then relays that message to the GIS client as the designated receiver (2). Once the selection has been performed the GIS client sends the results (3) back to the cockpit using the AppCom server (4).

The AppCom service has already proven to be a versatile and robust solution for the communication between apps. All of the client applications developed within the project integrate the AppCom client and expose part of their functions through its services. Additionally the experiences with the AppCom service also benefit the development of other services within the architecture like the EquiJoin service for managing object relationships (see Data Abstraction and Integration section for details). Security is a major concern when it comes to services like AppCom. While several mechanisms for securing the service and its session management have already been implemented, additional work is planned in this area. Guarding the service against potential vulnerabilities in its underlying communication infrastructure as well as the integration of AppCom with authentication and authorization mechanisms in an identity federation scenario still need to be addressed.

3.2 Authentication

3.2.1 Determining factors for authentication in a distributed system environment

The system landscape of the infrastructure management cockpit with its service-oriented architecture comprises a number of different and independent systems. Among others it includes the server providing the cockpit and app functionalities, data sources and clients. In such distributed environments with systems from different security contexts, authentication and authorization pose specific problems and requirements. The cockpit-users may are employees of different organizations and should be able to access the InfraGem applications through a Single-Sign-On (SSO). This necessitates a way to pass on user identity information (like credentials) between different, trusted systems in a secure manner. Ideally the users should even be able to authenticate themselves with the credentials of their own organization when accessing applications like the cockpit. This not only increases the ease of use but the decentralized user management also leads to a more up-to date user base. With a centralized user management the customers have to report all mutations concerning their users respectively employees to their providers. This process is often delayed which leads to situations where former employees still have active accounts on systems run by the providers. With the decentralized user management, where the respective organization are responsible for updating their own users, the usual mutations in the organizations own identity provider will automatically take effect for all service providers within the identity federation. This additionally helps to achieve the strict security requirements for restricting the access to personal data. On the provider side the management of rights should be handled in a uniform way within different application. Furthermore the new systems and applications for the cockpit have to integrate with the existing operational environment of the provider and the current GeoApps infrastructure.

3.2.2 SAML 2.0 based identity federation as a solution approach

To tackle these problems the project aims to implement a solution based on the principles contained in the eCH-0167 SuisseTrustIAM standard (Hassenstein et. al. 2014) which outlines a generic architecture and processes for Identity and Access Management across organizational borders. At its core is a broker infrastructure that allows for a qualified verification of attributes (roles) of authenticated subjects. The specific implementation will be based on the recommendations in the eCH-0174 standard (Laube-Rosenpflanzer et. al. 2015) describing requirements and recommendations for a SuisseTrustIAM implementation basing on the Security Assertion Markup Language (SAML) 2.0 protocol. This solution intends to implement an identity federation where the Identity Management (IM) is outsourced to the customer or its partners. A trust between the customer's Identity Provider (IdP; e.g. an Active Directory) and the Service Providers (SP; i.e. the application providing functions to the users) needs to be established. The authentication in this environment is based on the SAML 2.0 protocol. A central Metadata Service (MS) and Discovery Service (DS) serve as broker between the between the IM and SP which provide their metadata to the broker that in turn allows all involved parties to retrieve the information necessary for the identity federation to work. This kind of identity federation allows a user from any of the trusted IdPs to authenticate himself to all trusted SPs within the same federation.

3.2.3 Implementation challenges

A first proof-of-concept demonstrated the feasibility of such an identity federation. Different IdPs and SPs in separate domains have been integrated in a simple scenario with a central Metadata and Discovery Service. There are several identity management solutions (both commercial and open source) on the market that support SAML 2.0 and are already widely used. These solutions can all potentially be adapted for the identity federation planned by the project. On the technical side the specification and implementation of the receiver component for the Service Providers that allows the consistent handling of authentication and authorization in different application will pose more challenges. The eCH-0174 standard however contains some recommendations in that regard and work on an according component has begun. The biggest challenges concerning the establishment of the identity federation will be the organizational, political and legal in nature. On one hand the trust between the involved parties has to be established on an organizational level and also be secured by according contractual agreements. The domain description that contains the definition of the attributes and roles that have to be supplied by the IdP is also part of these agreements. The definition of the content and semantics within this domain description has to take into account things like organizational levels, functions and common operations among other things. Each IdP will have to map their internal users and groups onto these attributes in order to take part in the identity federation. Other projects have shown that reaching a common domain description poses a major challenge which still needs to be addressed for the InfraGem project.

3.3 Data access and integration

3.3.1 Determining factors for data integration in a service-oriented architecture

The cockpit depicts relevant information to the user based on data from different sources. The classic approach is to import the data from the necessary sources and to integrate it into a common data model within a data warehouse. This method was also applied in the first version of the management cockpit (Schaller et al. 2010). This approach will be partially retained for data that is not directly accessible using services. For the remaining data sources the goal is to always display up-to-date information using a service-oriented approach. This requirement and especially the rule-based combination of textual and spatial data necessitate a slightly different method than the data integration into a classical data warehouse. When a view is displayed in the cockpit, the corresponding data sources must be read and combined ad-hoc. This requires a solution that can read data from different sources and transform it into the needed form. This process may also involve the combination of data from different originators. Furthermore an easy integration of the solution with diverse applications has to be possible. This also requires that the data integration solution can be completely controlled through configurations in order to ensure reusability without changing the program code.

3.3.2 Challenges resulting from the combination of different data sources

The combination of data from different sources poses some challenges in particular. On one hand is the possibility of using identifiers to specify an explicit matching. This however requires stable identifiers on both sides. In practice spatial objects often have no stable identifier. Furthermore there is the question whether a change in geometry of an object is just an update of the data regarding the corresponding real world object or whether this object has actually been replaced with a new one (e.g. a sewer pipe was replaced due to leakage). The definition of certain criteria for testing the equality of an object may be one solution to this problem but has to be individually adapted for every model and object type. On the other hand there is the possibility of matching textual and spatial data using spatial operations. This however necessitates attributes on the textual data that can be used for geocoding.

3.3.3 Data Abstraction Layer with pluggable data adapters

Most available data tools are aimed at classical ETL (Extract Transform Load) processes that run periodically and work on large data volumes. While some of these tools also are able to work with spatial data they all have response times that are unsuitable for an instantaneous web based ad-hoc view preparation in our cockpit application. Most existing frameworks for the ad-hoc integration of data on the other hand can’t handle spatial data. Therefore the project developed a custom solution for data access and integration which is depicted in Figure 3.

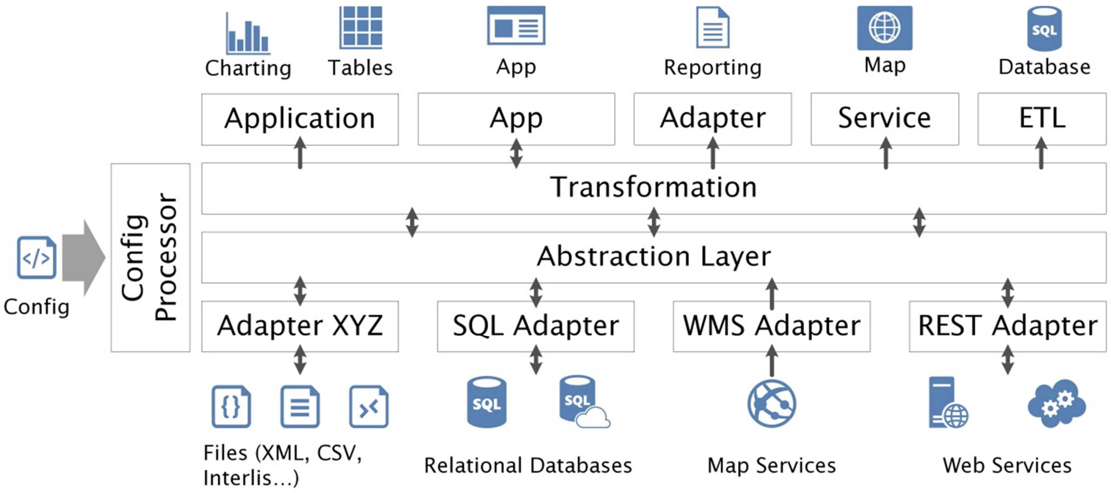

Fig. 3: Schematic view of the Data Abstraction Layer

A Data Abstraction Layer (DAL) that can be combined with source specific data adapters forms the basis of that solution. The source specific logic is encapsulated in the respective data adapter. A transformation layer on top of the abstraction layer allows for the combination of data from different sources as well as its transformation (e.g. filtering, aggregating or deriving new columns). This layer also supports spatial data types through a solution that builds upon the GDAL open source library. The definition, combination and transformation of data sources are controlled using XML configuration files that can be interpreted by a configuration processor. This allows for a completely declarative approach and easy reuse of data access solutions.

3.3.4 Application of the Data Abstraction Layer

The data integration solution is used in the GIS client, in services for creating charts as well as in generic data integration processes. The GIS client uses the solution to read and write data from sources in order to generate layers for displaying and editing that data. Raster formats are generated for display layers while a vector output is used for editing purposes. This distinction leads to a solution with good performance since the editing mode usually works only on a relatively small area which limits the number of vector objects that have to be handled. The same data sources used to generate layers on maps are also used by a web service that delivers data in a form suitable to be displayed in visualizations like charts. The common source data also allows implementing interactions between charts and maps (e.g. highlighting).

3.4 EquiJoin: a web service for managing references between independent data sources

Due to missing common and identifiers of the same real world object in different datasets an additional solution called EquiJoin has been implemented for managing references between objects from different source systems. Content classes are defined that include information about the specific source system, object type and identifiers. A specialised service built on top of the AppCom infrastructure then allows apps to create, read, update and delete references between two objects from registered content classes. An app only has to know the specifics about the objects in its own system while the objects of the other system are handled by the respective app and abstracted through the service. An example for the use of such references is the GeoDMS (spatially enabled Document Management System) which allows linking documents in SharePoint with spatial objects and vice versa. SharePoint only needs to know about its documents and their IDs while the specifics about the spatial objects are handled by the GIS client. The apps only have to know the respective content classes and they can manage the references for the links using the EquiJoin service. More applications of this solution exist within the cockpit (especially links between documents and project respectively measure).

4. CONCLUSION AND OUTLOOK

4.1 Conclusion

While the development of the web based cockpit is not yet complete, the first experiences are positive. The technical foundations for the service based architecture have proven to be viable. The first applications of the cockpit support the implementation of the infrastructure management in the pilot projects. It is able to show gaps and quality problems in the base data. While the municipalities have to work on these problems, the architecture has the advantage that it does not require a change of responsibilities or of the existing data maintenance processes, which facilitates this task. Thus the cockpit also supports the municipalities in developing and implementing their infrastructure strategies and lets them monitor their progress. On the operational level information provided by the cockpit supports the planning of investments and their optimization with respect to costs and financial constraints, therefore, also smoothing the peak of investments. As a whole the implementation of an infrastructure management strategy supported by the cockpit allows the municipalities to shift their roles from a reacting to an acting party.

4.2 Future work

However to enable the support of a holistic and sustainable infrastructure management through the cockpit, additional work concerning the integration of other infrastructures (e.g. water supply, roads, energy) will be necessary. First steps in that direction have been taken during a bachelor thesis concerning road management. Further data sources will have to be integrated into the cockpit, many of which can be found at cantonal and federal level. These existing data sources are however not only interesting for management instruments in municipalities. The team is also working on establishing cockpits as management instrument on the cantonal and federal levels. The goal is to achieve better networking inside and across organizations of the state, cantons and the local level (municipalities, associations of municipalities etc.) This will need measures on the technical, organizational, cultural as well as legislative level to allow the necessary exchange of data and information. These changes will not only facilitate the access to required data but also enable benchmarking between organizations.

Besides making additional data sources available the team also aims to integrate additional instruments into the cockpit. The goal is to make the cockpit the central point of entry for accessing instruments including investment and financial planning, budgeting, measure planning, project planning and document management amongst others. At the same time work on better linking management instruments and management processes is necessary.

4.3 Vision of a Swiss management infrastructure

Integrating data sources from different federal levels into cockpits for municipalities or establishing isolated cockpits on cantonal and federal level are only first steps towards the vision of a Swiss management infrastructure. The goal of the future management infrastructure is to create linked management instruments spanning the governing bodies of all federal levels in Switzerland. The management instruments are to provide the governing bodies at the right time with data relevant to the respective questions from the best maintained sources independent from the physical location of the data or who the data owner is.

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BIOGRAPHICAL NOTES

Simon Hofer leads the engineering and operations of Geocentrale datacenter and software development team of Geocloud. He obtained a Bachelor of Science in Information Technology from the Bern University of Applied Sciences (BUAS) in 2010.
He has several years of experience in spatial data integration processes, software and systems engineering of IT infrastructure and spatial enabled data centric systems. His current focus lies on the development of spatially enabled systems which integrate with the data centric world as a service e.g. a document management systems enhanced by the spatial aspect (GeoDMS).

Christoph Schaller is a research assistant working for the ICT-Based Management Institute of the Engineering and Information Technology division of the Bern University of Applied Sciences (BUAS). He obtained a Bachelor of Science in Computer Science from the BUAS in 2007. After graduation he began working for the BUAS as an assistant in R&D projects. In 2011 he also obtained a Master of Science in Engineering Bern University of Applied Sciences in Internet and Communication Technologies. He has several years of experience in Business Intelligence development which he also teaches in bachelor and continued formation programs. Besides the application of Business Intelligence in management cockpits for public management his current focus lies on the combination of management instruments and spatial data.

Patrick Haring is a Software and Security Engineer in the software development team of Geocloud. He obtained the Bachelor of Science in Computer Science from the Bern University of Applied Sciences (BUAS) in 2015. Until February 2015 he was working for the BUAS as an assistant in R&D projects e.g. a management cockpit for public management. He has several years of experience in application development. His current focus lies in the development of secure spatially enabled systems.

Jürg H. Lüthy is member of the Management Board at SWR Geomatik AG, one of the largest geomatics companies in Switzerland. He obtained a master's degree in 1996 from Federal Institute of Technology Zurich (Switzerland) in Rural Engineering and Survey. From the same institution he holds a PhD (2007). He has many years of experience in spatial data management, transition from paper maps to data centric systems and the operation of Spatial Data Infrastructures. His current focus lies in the provision of holistic information using modern web-technologies like building the technical infrastructure for Cadastre of Public-law Restrictions on landownership. He is the Swiss delegate to FIG Commission 3.

CONTACTS

Simon Hofer
Geocloud AG
Wagistrasse 4
8952 Schlieren
SWITZERLAND
Tel. +41 43 501 53 11
Fax +41 43 501 53 29
Email: simon.hofer@geocloud.ch
Web site: www.geocloud.ch

Christoph Schaller
Bern University of Applied Science
Institute for ICT-Based Management
Höhenweg 80
2501 Biel
SWITZERLAND
Tel. +41 32 321 64 79
Fax +41 32 321 65 23
Email: christoph.schaller@bfh.ch
Web site: www.ictm.ti.bfh.ch

Patrick Haring
Geocloud AG
Wagistrasse 4
8952 Schlieren
SWITZERLAND
Tel. +41 43 501 53 12
Fax +41 43 501 53 29
Email: patrick.haring@geocloud.ch
Web site: www.geocloud.ch

Jürg H. Lüthy
SWR Geomatik AG
Wagistrasse 6
8952 Schlieren
SWITZERLAND
Tel. +41 43 500 44 48
Fax + 41 43 500 44 99
Email: juerg.luethy@swr-geomatik.ch
Web site: www.swr-geomatik.ch