Linked Data in the AEC: A case-study on the application of Linked Data for Cost Control

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ABSTRACT

Typical characteristics of the Architecture, Engineering & Construction (AEC) industry include the many temporary collaboration partnerships (for the production of constructions), the focus on projects, and the heavy involvement of the client in the process. Due to these characteristics, the AEC industry can be described as a complex systems industry. Furthermore, the complexity of works, inaccurate evaluation of project performance, and risks and uncertainties, strongly perform as cost control inhibiting factors. This resulted in a need for close collaboration of parties throughout the entire life-cycle of a construction. A more effective approach to the management of information from these numerous disciplines is required. Processing information from a variety of sources and disciplines is a human-intensive process and requires specialized human resources. Presenting data in a computer processable format can greatly reduce the needed amount of human resources and improve the efficiency. The use of semantic web technologies is often regarded as a tool to improve interoperability in the AEC industry. Furthermore, semantic web technologies such as linked data make it possible to visualize information in structured graphs and integrate digital construction information of different nature. Linked data is a term for describing a method for publishing, sharing and connecting data, information and knowledge on the semantic web with the aid of uniform resource identifiers (URI's) and the resource description framework (RDF). The authors propose in this paper that the application of linked data creates more and faster insight (into the state of affairs) with the same data regarding cost control in infrastructure projects. With the use of a literature study, a case study, and a proof of concept, this research provides evidence that existing project data can easily be transformed into RDF/XML and that linked data can be applied for cost control in the construction industry. This, in turn, can help contractors to speed up their decision-making processes and make more substantiated decisions.

Author keywords: Linked Data, Semantic web, Cost Control, AEC, RDF, construction management

1 Introduction

The AEC industry can be characterized as a complex systems industry due to the temporary coalitions of companies to the production of construction, the focus on projects and the heavy involvement of the client in the process (Winch, 2003). Furthermore, a need for close collaboration of parties throughout the whole life-cycle of a construction arises, due to the division into the many disciplines of the AEC industry. An important process within the financial discipline is 'cost control'. It is observed that the complexity of works, inaccurate evaluation of project performance and risks, and uncertainties strongly act as cost control inhibiting factors (Olawale & Sun, 2010). Furthermore, Frimpong, Oluwoye, & Crawford (2003) and Rahman, Memon, & Karim (2013), describe three cost control inhibiting factors as "lack of coordination between parties", "waiting for information" and "slow decision-making". This requires an effective approach to the management of information from these numerous disciplines (Aziz et. al (2004), as cited in Pauwels, Zhang, & Lee, (2017).

Pauwels et. al (2017), states that the concept of Building Information Modelling (BIM) in the AEC industry has led to a paradigm change in the way the AEC industries define, adjust and manage the semantics of product models closely linked to geometry. The use of semantic web technologies is often regarded as a tool to improve interoperability in the AEC industry. Yang & Zhang (2006) state that this is due to the issues and opportunities that lie with the collaborative processes that often involves multi-disciplinary project teams at external building sites with a variety of business process support applications. All while their models are shared with parties that have a semantic, structural and syntactic difference. For example companies might have (1) a different understanding of the same concept or naming of objects (semantic difference), (2) different design applications with multiple data sources stored in different data structures (structural difference) or (3) different data formats and fundamentally different languages are used in the exchange processes with and within companies.

Pauwels, Zhang, & Lee (2017), further state the incentives to the use of semantic web technologies, as "the desire to connect to various domains of application that have opportunities to identify untapped valuable resources closely linked to the information already obtained in the AEC domains"; and "a desire to exploit the logical basis of these technologies". In conjunction with this statement is the research by Yue, Guo, Zhang, Jiang, & Zhai (2016), in which the publishment of geospatial data of heterogeneous geospatial sources is performed according to linked data. They conclude that the combination of linked data and web geoprocessing workflow not only supports semantic discovery- and integration of various geospatial resources, but also provides transparency in data sharing and processing. Yue, et. al (2016), further state that this has led to an industry-wide interest in sharing and organizing the semantics[1] of a construction during its entire life-cycle. The industry not only focuses on adopting a software application, rather it progresses towards a semantic structure and a well-organized semantic connectivity map.

Furthermore, Niknam & Karshenas (2015), state that "The process of understanding information that is created in other sources is human-intensive and requires the employment of specialized human resources. Presenting the required information for cost estimating in a computer processable format can greatly improve estimator's efficiency". One method by which this can be done is linked data.

The philosophy of linked data stems from the idea of using the web to link data and aims to transform the web into a worldwide database (Radulovic, et al., 2015). According to Pauwels, Zhang & Lee (2017), semantic web technologies such as linked data make it possible to integrate construction information of different nature (e.g. Geographical Information System (GIS) data, city data, material repositories, regulation data, and cadaster data) and visualize data in structured graphs.

Linked data is a term for describing a method for publishing, sharing and connecting data, information and knowledge on the semantic web with the aid of uniform resource identifiers (URI's) and the resource description framework (RDF). By applying the linked data method, internet users can integrate physical world data and logical world data in order to draw conclusions, create business intelligence, enable smart environments, support automated decision-making, etc. (Yu, 2016). Front runners in the use of semantic technologies are mostly large data-driven companies such as Facebook, Google and LinkedIn, and governmental agencies such as municipalities and ministries ((Geonovum, 2018) and (Luiten, 2017)) who publish their data publicly.

While there has been numerous research done on linked data, and linked data is already being applied by several companies, no applications of linked data for cost control in the AEC industry have been found by the researchers. However, an application of semantic web technologies for construction cost estimating, which takes place before the construction phase, has been found in the research by Niknam & Karshenas (2015). In this research, a flexible estimation application has been made that is able to access, and use independently created domain knowledge via the internet. With the use of ontologies, RDF, and Simple Protocol and RDF Query Language (SPARQL) data from a BIM knowledge Base and an estimating knowledge base is linked to suppliers knowledge bases.

Linked data is only a part of the semantic web. The semantic web envelops the idea of publishing and linking all data together on the web (Berners-Lee, Hendler, & Lassila, The Semantic Web, 2001). Although since the beginning an increasing amount of data was put on the internet, the data itself was not linked to other data. In order to cope with the growing amount and complexity of the data, Berners-Lee (2018), laid out the four rules of linked data as follows "(1) Use URI as names for things, (2) use HTTP URI's so that people can look up the names, (3) as soon as someone searches for a URI, provide useful information using the standards RDF and SPARQL and (4) add links to other URI's so they can discover more things (Berners-Lee, Linked Data, 2018)."

The first rule stems from the need to define unique names so objects or things will not get confused. The second rule enables people or computers to look up the names. Applying the third rule enables publishers to write data in the form of triples and give information about a resource. Triples are part of the RDF and are a set of three entities that give a statement about the semantic data in the form of subject, predicate and object properties. The format makes it possible to display knowledge in a way that both programs and humans can read it. Using the RDF format, information is linked to each other using semantic triples. An example of this is "Bob is interested in the Mona Lisa". The object is 'Bob', the predicate is 'is interested in' and the value is 'the Mona Lisa' (Schreiber & Raimond, 2014).

Semantic technologies commonly used with linked data include: the standard RDF; RDFS, the data-modelling vocabulary for RDF data (Brickley & Guha, 2014); OWL, the extension of RDFS and a ontology language for the Semantic Web (Patel-Schneider, 2004) and; SPARQL, the standard semantic query language for Linked Open Data on the web (Ontotext, 2018). The integration of these technologies helps to integrate and to reason about data on the web.

Linking data is a painfully manual job when databases describe the same objects with different identifiers. Berners-Lee, Hendler, & Lassila (2001), state that a program that wants to compare or combine information across the two databases has to know that these two terms are being used to mean the same thing. Ideally, the program must have a way to discover such common meanings for whatever databases it encounters. A solution to this problem is the use of ontologies. Euzenat & Shvaiko (2013) describe an ontology as follows: "An ontology typically provides a vocabulary describing a domain of interest and a specification of the meaning of the terms in that vocabulary". It is the formal naming and definition of the types, properties, and interrelationships of the entities

[1] Semantic technologies use formal semantics to give meaning to data.

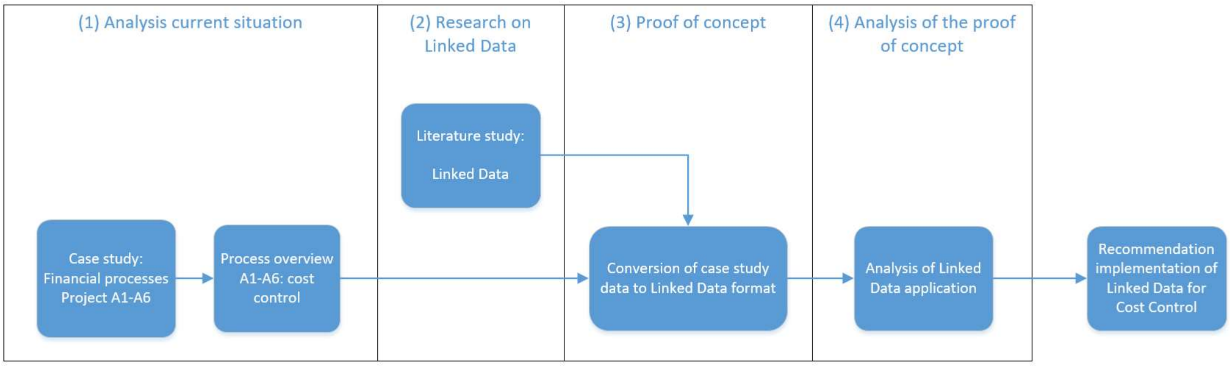

Fig. 1. Research model

in a particular domain (Yu, 2016).

Linked data is slowly making its entry into the AEC industry. As mentioned by Eisenzopf (2016), the progress with linked data is mainly centered in academia. He further suggests that this is due to the learning curve of linked data standards. “Linked data is just too complicated” (Eisenzopf, 2016). Apart from research in the field of linked data in the AEC industry, there is a linked Building Data Community Group within the W3C. Also, a Linked Data Working Group as part of the Technical Room of building SMART was founded (Bonduel, Oraskari, Pauwels, Vergauwen, & Klein, 2018).

This research focuses on the application of linked data for cost control. The hypothesis of this research is that the application of the linked data method on project data enables more and faster insights in the financial data in order to carry out cost control in the execution phase of an infrastructure project. In order to test the hypothesis, three sub-questions have been drafted: (1) “What is the current financial project control process during the project execution phase and what obstacles occur regarding the financial project monitoring?” (2) “How can we apply the linked data method for the use of cost control within infrastructure projects?” and (3) “What are the preconditions and the pros and cons of applying linked data related to the financial project monitoring in the construction phase of an infrastructure project?”.

2 Methodology

In order to answer the previously stated research questions, a research model has been drafted as presented in Fig. 1. The model has been drafted according to the methodology of Verschuren & Doorewaard (1998) and has been divided into four parts wherein each part aims to answer one of the previously stated sub-questions. The first part consists of a case study of the infrastructure project A1-A6. The second part of the research focusses on the literature on linked data. The third part is the development of a proof of concept of linked data wherein project data from different disciplines is linked and visualized using the linked data method. With the use of the proof of concept, evidence is provided that linked data can be applied within the construction industry. The fourth and last part consists of analyzing the proof of concept and drawing conclusions. The following chapters will each elaborate on a part of the research model and the corresponding research methods and sub-questions.

The first sub-question on the analysis of the current situation is answered with the use of a single-case study consisting of interviews and a document research on the financial processes of the project A1-A6. The case study was performed on an infrastructure project in which the company VolkerWessels participated. In order to ensure the access to the project information, a recent project was chosen, being the project A1-A6 Schiphol-Almere-Amsterdam. Furthermore, as the project execution phase was recently finished in October 2017, information on the whole of the project was available where it would not be the case in an ongoing construction project.

The research methods in the case study consisted of semi-structured interviews and a document study. Before planning the interviews, the researcher participated in a five-day workshop on “from tender budget to start budget in 30 days”. During this workshop, fifteen financial experts and cost controllers from the operating companies of VolkerWessels participated. During this workshop, the researcher gained more insight into the structures and obstacles of the financial processes. The information obtained in the interviews was used in the successive interviews and access to the documents was arranged via the interviewees. The interviews were recorded and subsequently transcribed. In the semi-structured interviews, the topics discussed were:

- the financial processes and information structures,
- the obstacles and problems that occur,
- the ‘ideal’ cost control situation,
- linked data,
- the possibilities of linked data for the cost control.

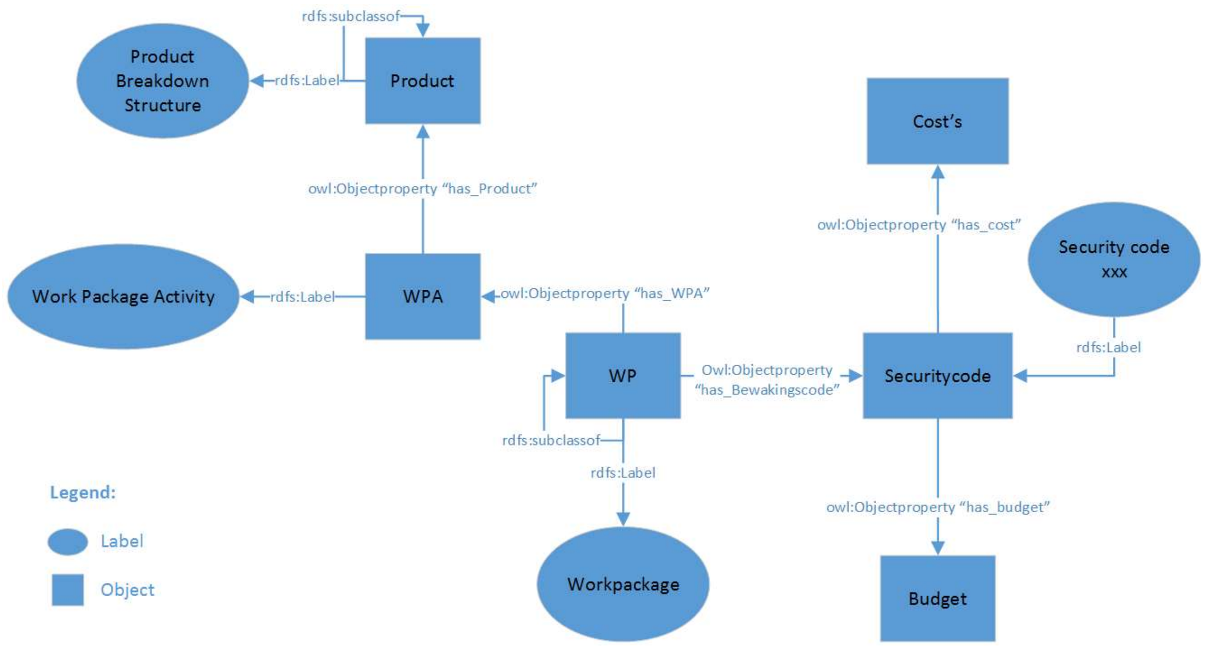

Fig. 2. Visualized ontology of the proof of concept

The interviewees were chosen for their positions in the financial department, their participation in different phases of the project A1-A6 and their participation in the development of the financial processes within their companies. This resulted in four interviewees who participated in different phases of a construction project. Furthermore, the interviewees all worked within daughter companies of VolkerWessels that participated in the project A1-A6. The first interviewee had the function of calculator for Van Hattum & Blankevoort (VHB) and focuses primarily on the tender phase. The second interviewee had the function of project controller for VolkerInfra and was also the head of the Enterprise Resource Planning (ERP) system development workgroup. This is workgroup focusses on the development of a single method of working with the same ERP system for VolkerWessels daughter companies in the infrastructure branch. The third interviewee had the function of project administrator for VHB and participated in the project A1-A6. The fourth interviewee had the function of project controller for VolkerInfra and also performed this job in the project A1-A6. With the use of these interviews, a process overview was made (Annex A) visualizing the financial processes within a construction project. Validation of the process overview was done with the use of two validation sessions with two of the experts earlier interviewed. These were the project administrator of VHB and the project controller of VolkerInfra who also leads the 1-ERP workgroup. In these validation sessions, a printed financial process overview was discussed, and the interviewees made notations on the printed process overview. During these sessions, also unclarities about the financial process overview were discussed. The author recorded and transcribed these sessions.

To find an answer to the sub-question "What is linked data and how can it be applied in de AEC industry?", a literature study has been performed. Using the online access of the University of Twente to several journals and the annexes in the papers found, other papers corresponding to this literature study were gathered. However, after extensive research in university- and online databases, no literature was found on linked data applications for cost control in the AEC industry. This could mean that no previous research has been done on this subject. Keywords used in the literature study were: Linked Data Linked Open Data, RDF, Semantic Web, Construction industry, AEC, cost control and OWL.

The proof of concept discussed in chapter 4 was used by the researcher to visualize possibilities of linked data implementation within the construction industry. Furthermore, by developing the proof of concept, insights were gained on the application of linked data within the construction industry. This research strategy has been chosen for the high relevance with practical disciplines and is mainly used in the testing of new technological developments (Verschuren & Doorewaard, 1998).

The proof of concept consisted of project data, from the project A1-A6, designed conforming the linked data methodology. The project data was gathered in the case study and consisted of data in the online (relational) database software called Relatics and data in Excel files. The data has subsequently been gathered all together in the program Relatics. In order to construct the project information according to the linked data methodology, an ontology was defined and visualized by the researcher (Fig. 2). Secondly, both financial and project general project data of four bridges was used to give an example of project data according to the linked data format. The financial data consisted of budget codes, budgets, and costs. The project data consisted of work package activities, activities, and the object breakdown structure. These two data groups were then used to provide evidence of the linkage of

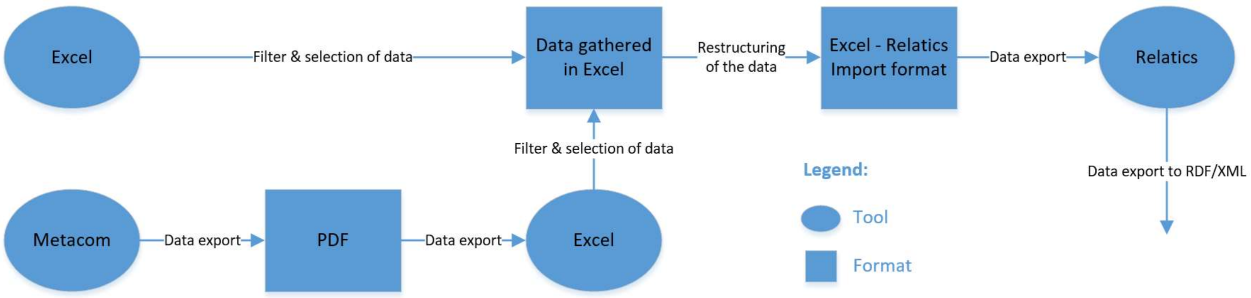

Fig. 3. Financial data transformation steps

the financial and project data and the reduction of the time needed to gain insight into financial data. Following, the project information was exported directly from Relatics into the structure as described in the ontology in Fig. 2. With the use of an online rdf viewer, the exported project data was visualized, and queries were performed on the data.

With the use of the interviews and the document study, access was obtained to the project and financial data from the construction project A1-A6. In order to keep the amount of data manageable, the financial data, such as budget codes and the costs, of four bridges of the project A1-A6 was collected. The bridges were chosen for their similarities and because they all belong to the same sub-project within the A1-A6 project. The product and work package activity (WPA) data were also gathered for these four bridges. The work package (WP) data, however, was gathered of the whole civil structures discipline within A1-A6. These WP's were primarily executed by Van Hattum & Blankevoort.

The financial data was gathered from excel files and the ERP program Metacom, and exported to PDF as can be seen in Fig. 3. Subsequently, the data was gathered in Excel and then filtered and selected. As the data needed to be in turtle format (TTL) for the SPARQL-visualizer, the data was first brought together in the program Relatics, so that the data could then be exported to the correct format. Since Relatics also works with an object-relationship-object structure, an export file that would transfer all the desired data to the turtle format could be written. In order to import the data in Relatics, the data needed to be restructured to Parent-Child relationships. As the budget codes are grouped together per bridge, de groups were linked in Relatics to the corresponding WP on the level of the bridge as a whole.

The construction data was exported from the A1-A6 project environment in Relatics in order to filter and select a sample. The sample consisted of the WP's and WPA's. Thereafter the data sample was imported into a Relatics environment, created for this research. The product group was manually added to the Relatics environment as it was small in number. Similar to the financial data, the project data was also restructured in Excel and then imported in Relatics using Parent-Child relationships in the import files (Fig. 4). The gathered sample data in Relatics was then exported to RDF/XML. By making an export file, it became possible to alter data in Relatics and then export it to a prescribed data structure. The export file was made using the standard Extensible Stylesheet Language Transformations (XSLT). Using this method, instances could be altered or added, without altering the XSLT export file as long as the data groups remained the same. The RDF/XML documents were checked with the use of the w3.org 'RDF validation service' for its syntax. The links between the nodes were visualized with the use of the online graph visualizer "http://visgraph3.org/" and then it was visually checked if the object groups were linked. Using this iterating process, the XSLT export file was optimized until no errors were found.

Finally, the RDF/XML sample document was converted to RDF/TTL format in order to use the data in the SPARQL-visualizer on (Holten, 2018). For the conversion, the web application 'Easy RDF Converter' (Humfrey, 2018) was used after which the RDF/TTL sample document was validated using the 'IDLab Turtle Validator' (IDLab - Ghent University, 2015). Although for the project data multiple steps were taken, this can also be avoided. For this research, all data was collected in a separate project environment which resulted in the copying and

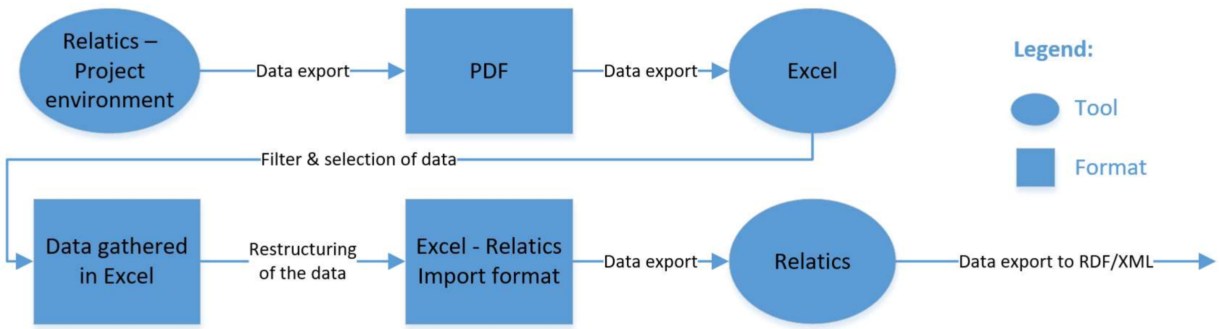

Figure 4: Project data transformation steps

manually transcribing of project information. The working proof of concept consists of the data gathered and exported to RDF/TTL which was then imported in a SPARQL visualizer. Using the SPARQL-visualizer, queried data can be visualized. For current or future projects, data can be directly exported from Relatics to RDF/TTL format making it even more easy as it doesn't need to be transferred to another digital project environment. Performing these steps, several kinds of data has been collected and transformed into RDF/TTL.

3 Case study – A1-A6 Schiphol-Almere-Amsterdam

As stated before, the case study consists of multiple interviews with the focus on cost control during the execution phase in the project A1-A6. Using the interviews a financial process overview was made and A1-A6 project- and financial data was collected for the proof of concept. Commissioned by Rijkswaterstaat (Rijkswaterstaat, 2018), the A1/A6 project was won by the consortium SAAONE, consisting of the companies Hochtief, VolkerWessels, Boskalis, and DIF. The project covered the widening of the road, the construction of several bridges and the construction of sounds barriers. VolkerWessels has built 81 constructions in the project of which 32 are a bridge. The operating company Van Hattum & Blankevoort was primarily responsible for building these constructions and the case study will, therefore, focus on Van Hattum & Blankevoort and VolkerInfra.

3.1 Financial process overview A1-A6

Using the interviews, a financial process overview was created by questioning the interviewees on the steps they have to take, the products they deliver, the information they need in order to do their work, and the information they have that others would need. The financial process overview in ANNEX A is divided into three phases; the tender phase, the design phase, and the execution phase. Each phase has its own cost control characteristics and products.

During the tender phase and the design phase, cost control was performed with the use of the monitoring technique 'Leading parameter'. This monitoring technique consists of choosing critical parameters which will represent the rest of the project, or, section (Al-Jibouri S. H., 2003). For example, in the A1-A6 project, one of the critical parameters measured was the amount of concrete to be used in constructions. Although variances of the parameters are clearly shown by this method, it does not state the reasons why.

The results of the monitoring technique were during the tender phase recorded in an integral cost overview (IKO). In this document financial data of multiple operating companies were combined to create a single overview of the cost of a construction. During the design phase, the results of the leading parameter technique were recorded in critical quantity overviews (KHO). Furthermore, in order to compare the costs during the design phase, critical parameters were updated for each process step. This results in an overview of the critical cost during the process sub-phases (1) starting budget, (2) sketch design, (3) preliminary design and (4) final design. However, when examining the KHO documents, it showed that for the final design the cost of the final phase would often not be filled in. When the interviewees were further inquired about this deviation they stated that often the time to fill the KHO in isn't taken and costs are already managed in the operational budget.

During the project execution phase, however, the type of measurement for cost control is changed to both 'activity-based ratios' and 'variances and earned value analysis'. According to Al-Jibouri and Mawdesley (2001), the variances and earned value analysis is the most common technique used as it gives the variances between two values. For example, budget and costs. The activity-based ratio consists of three ratios, the planned performance, the actual performance, and the efficiency.

3.2 Data structures A1-A6

During the interviews, it became evident that the information structures in the financial processes differ for each project. The project structure is decided on in the first phase of the process. As the demarcation for each project could focus on phasing, objects, area's and discipline, the information structures differ with each focus. In order to coop with the everchanging data structures, operating companies have their own data structure and workflows within their companies resulting in a large diversity of processes and data structures that are being tried to put together each project. That this leads to ineffective or unnecessary work was told in an interview with the project controller of VolkerInfra. The interviewee described the difficulties of connecting financial data to objects, after which he was presented the results of a previous interview, in which could be seen that the operating company usually connects the financial budget codes to an object. Furthermore, he was also unaware that the budget codes can be divided into two subparts; the object code and the activity code.

Most project information such as planning, work activities, inspections, standards, and design are linked in

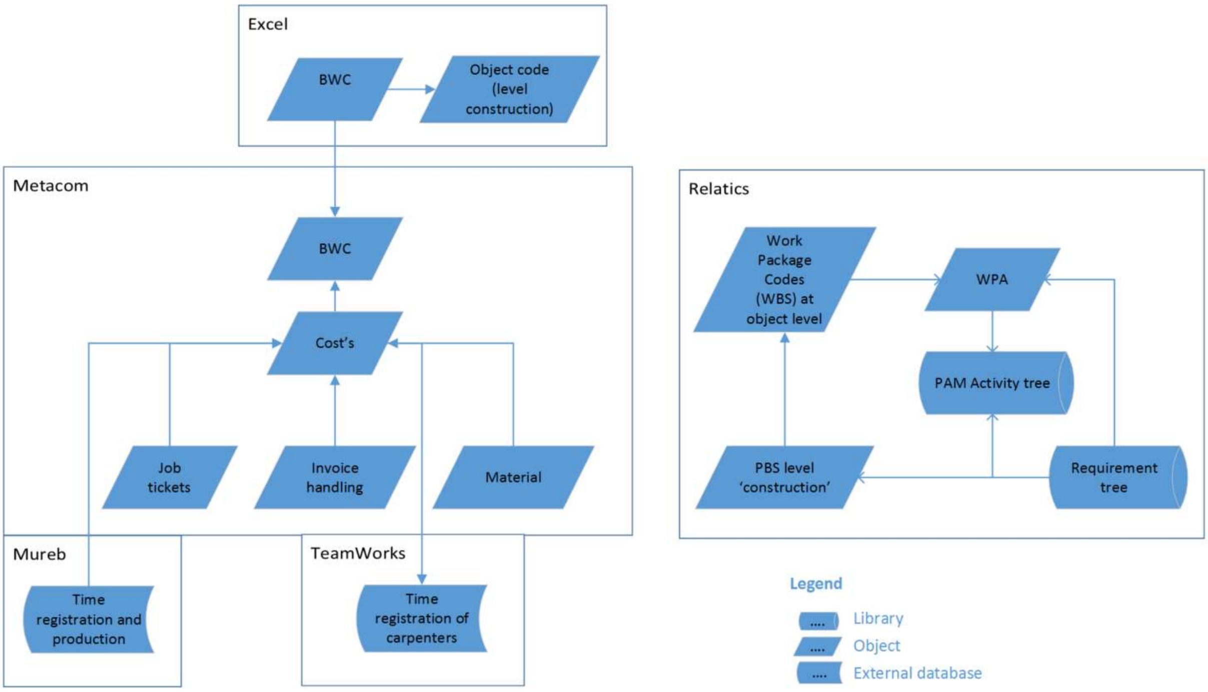

Figure 5: Current project data structures at VolkerInfra

Relatics and linked based on the work packages and work activities (Fig. 5). The financial project information during the execution phase, however, is recorded in a separate ERP system called 'Metacom'. Furthermore, the financial information is registered per budget code (BWC) which does not connect to the work activities as can be seen in Fig. 5.

At VolkerInfra the data structures are currently being linked and analyzed with the use of data warehousing and visualized with PowerBI. Its function is to link 'data silos' to each other in order to perform analyses on the data. However, currently, the work packages and sub-objects aren't linked with the financial data such as budget codes. Furthermore, as budget codes are made at the end of the project design phase, design and work packages are made without taking the budget codes into consideration.

3.3 Cost control inhibiting factors

In the interviews, several cost control inhibiting factors came forth confirmed by multiple interviewees. In this chapter firstly, the obstacles are discussed that are construction phase transcending, after which obstacles are discussed that occur specifically during a phase. Finally, the ideal cost control situation of the interviewees is discussed.

Similar to the problems of a complex industry with the temporary collaboration with parties, the interviewees noticed the difference in the cost control approach between collaborating parties. Furthermore, even between projects performed by the same company a difference in cost control approach was seen. Construction projects are rarely completely similar to another project and the differences in project demarcation force construction companies to change their approach per project. For example; where one company would subdivide a bridge into 5 main components, another company would subdivide the bridge into 6 main components.

Another obstacle defined by the interviewees is the difference in the naming of objects. A simple example from the case study is for instance; where one company would call an object a 'bridge', another company called it a viaduct. While it might seem like people would be able to manually solve this, the obstacle becomes much more complicated when it concerns technical jargon, object codes, activity codes and etc. Specific for cost control the difficulties of using different programs was also mentioned.

Throughout a whole project, different programs are used and information is exchanged between them. However, this often is done manually as each company, and each discipline within a company has the need for programs that meet their specific needs. Cost controllers have to connect information from different excel files and programs by constantly copying and importing data from one program to another. This makes it a demanding manual task to exchange information between these programs. For example, during the tender phase quantities from a 3D model are manually exported to a calculation program called IBIS. Thereafter, when a tender is won, the calculation is manually extracted and imported into another calculation and cost control program called Metacom and all the while reports are made in Excel. This in turn also causes problems with the use of correct versions of documents as the excel documents need to be manually updated each time the data in Metacom changes.

3.3.1 Tender phase

Two cost control inhibiting factors, specific for the tender phase, are both related to the use of information that was created during other phases. The first concerns the fact that the budget of objects, drafted during the tender, is rarely are used to compare the cost during construction. Designs, and thus also costs, often change during the design phase. Furthermore, as not all object-, activity- and budget codes are made in the design phase, it becomes very hard to automatically link costs from the construction phase to the budget, made in the tender phase. This, in turn, makes it very hard for the tender calculators to find the actual costs of constructions. A standard operating procedure for giving feedback to the tender calculators was also not defined.

3.3.2 Design phase

There was only one cost control inhibiting factor mentioned occurring specifically during the design phase. As collaborating companies often each design a part of the construction, they also use their own project demarcation for cost control. When all budget designs of the collaborating parties are then collected, it is only possible to combine the budgets at a high level. This is due to both the semantic difference in the naming of objects and the difference in project demarcation. As a result, it becomes a laborious job to manually collect the right financial data and asses what the exact costs are of an object or sub-object.

3.3.3 Construction phase

Several of cost control inhibiting factors specific for the cost control are related to two themes being (1) data structures and (2) the tension between collecting a lot of data and the desire of the contractor to administrate less information. The problems, related to the data structures, consists of the impossibility to link budget codes to work package activities and the difficulties in determining the costs associated with a specific object within the project. The project information such as planning and design is often linked to the work package activities and the financial information to the budget codes. However, as the work packages and budget codes are not aligned with each other, it becomes very difficult to link the two. Furthermore, as both are used in fundamentally different programs, exchange between the two becomes a laborious job of copying and pasting the data. The second obstacle arises from the different types of costs the different associated methods of cost control. During construction often equipment such as cranes is used for multiple constructions making it difficult to assign the costs of that crane to a specific object.

Related to the second theme, three obstacles were defined. The first obstacle is the terms in which cost control is applied. Only every four weeks financial data from the construction site is collected in order to perform cost control. Although for large deviations a contractor will directly report the deviations, this results in a time lag of the analyses of the projects. This, in turn, results in the management taking decisions based on four-week-old data. Directly related to this first obstacle is the second obstacle. For accurate cost control, a large quantity of data is needed. However, as this larger amount of data takes longer to process and as it will generate more information to administrate for the workers at the projects, a tension field arises. The third obstacle obtained in the interviews is the missing feedback loop of the actual financial costs to the tender calculators. Currently, there is no standard protocol to return financial data of a project to tender calculators in order to verify the used unit prices.

3.3.4 Ideal cost control situation:

A theme that came strongly forward during all interviews, was the automation and linking of data and/or programs. An ideal cost control situation for the interviewees would be to have a dashboard in which real-time data would be shown and where the financial expectations would automatically change with changes in a project. This ideal situation seems to originate from the tension field of wanting to have a large quantity of accurate data while the administrative load, for the contractor and the cost controller, does not rise. Furthermore, as analyses and information exchanges are often done manually, cost controllers wish to automate these actions in order to speed up the process, diminish the chance of human errors and deliver more accurate information to the management. However, a limiting factor is the collection of data. As gathering more data would give the administration of projects an increasing workload it would be difficult to implement. A solution to this problem could be the application of monitoring technologies.

4 Proof of concept - Linked data application at VolkerInfra and operating companies

From the case-study it was derived that the major opportunity of linked data for cost control during the execution phase, can be found by linking the work packages with the financial budget codes. In order to develop a working proof of concept, project data had to be recorded according to the linked data principles. Data of the project A1-A6 has been collected and a blueprint was made of the data structure (Fig. 2) to be used in the proof of concept.

```
PREFIX rdfs:
<http://www.w3.org/2000/01/rdf-schema#>
PREFIX owl:
<http://www.w3.org/2002/07/owl#>
PREFIX vi:
<https://vise.volkerinfra.nl/>

CONSTRUCT {
  vi:WP-00632 owl:has_Bewakingscode ?v .
  ?v rdfs:label ?label
}
```

Fig. 6. Query 1 - requesting the budget codes linked to work package WP-00632

As can be seen in Fig. 2, six different object groups have been selected to be included in the proof of concept. The collected data groups are the products, the work package activities (WPA), the work packages (WP), the budget codes, the budgets, and the costs. These data groups have been chosen as they together cover project activities, object structures, and the budgets and costs.

Applying the linked data method can be done at two moments; (1) when storing new data according to the linked data principles and (2) when transforming data already present, in order to make them comply with the linked data principles. Although the first method is preferred to do, it was not possible for this research and only data currently existing was used. Using this second method did, however, show how data from multiple sources could be transformed and used.

In order to filter and bring fort the desired RDF/TTL data, queries had to be written. For the proof of concept, four different queries are written of which each one focusses on a desire of the cost controllers, established from the interviews. The queries have been made in order to provide proof for (1) the workability of the proof of concept and (2) to prove the added benefit of linked data compared to the current situation at VolkerInfra. Via a web browser, the personalized online SPARQL-visualizer (Sluijsmans, 2018) can be opened, in which the queries are prescribed in the description. The RDF/Turtle data, however, is not included as it contains confidential information. The data can be pasted or written in the application. The following four queries have been performed on the data in the SPARQL-visualizer:

- Query 1: Requesting the budget codes linked to a specific work package.
- Query 2: Requesting all the data that is linked to a single product such as a bridge.
- Query 3: Requesting the budget codes, budgets, and costs that are linked to bridges with a specific sub-product.
- Query 4: Requesting the budget codes that are linked to work packages with a specific work package activity.

With the use of the first query, shown in Fig. 6, a link is used between the financial data and the work package. This query presents the budget codes linked to a specific work package, making it possible to perform cost control per work package. The second query presents all the data that is linked to a specific object including both project and financial data. In the second query all work packages, work package activities, budget codes, budgets, and costs are shown, making it possible to find financial data that complies with being connected to a specific product. Performing the third query, all financial data is gathered that is linked to a product containing a specific sub-product. Using the link from product to work package and from work package to the budget codes, financial data could be collected on the product level of a construction as a whole. For instance, using this query, data could be gathered on bridges with a specific type of foundation or a specific type of deck-railing. This data then makes it possible to compare the financial data of bridges consisting of similar characteristics. The fourth query presents the financial data that is linked to a specific work package activity. With the use of this query, financial data that is linked to a work package containing a specific work package activity is collected. For example, the query will present all the costs and budgets of a construction in which drainage is applied.

It was noticed that when attempting to link the financial data to activities, multiple levels of activities could not be linked to the financial data. Even though simple structured data was used of four bridges, issues arose due to the separation of the activities in phases while this isn't done with the budget codes. Furthermore, as the two disciplines record data differently and often even have a semantic difference, data could not yet be automatically linked to each other and manual interpretation was necessary.

In the scale model, a large benefit of linked data for cost control can be found in the filtering of financial data based on project data. Currently, this can be (and is) done manually and sorting through the different files and programs is a laborious task. When data is recorded according to the linked data principles, the search task for the right financial data can be done with a single query eliminating search time. As the data is available online, chances of using dated data become less.

5 Discussion

In this paper, the authors argued that the application of linked data is an added value for the cost control of infrastructure projects during the execution phase. In the case study, the financial processes were mapped and in the proof of concept the application of linked data was determined where the biggest advantage was expected. In this section, the results will be discussed of (1) the case study, (2) the results of the proof of concept and (3) the opportunities of linked data and the implication for the AEC industry. This chapter concludes with the limitations of this research.

The case study consisted of four interviews of which two interviewees were involved in the verification of the financial overview (Annex A). Using the interviews, the financial process overview was made and the data structures were mapped. The interviewees consisted of an equally divided amount of people working for VolkerInfra and Van Hattum & Blankevoort and the interviewees provided access to the data of the project A1-A6. Fig. 2 visualizes the data structure during the executing phase of the project A1-A6. All interviewees agreed on the fact that the financial data was not directly linked to the project information. There was a clear gap in information exchange and linkage between the financial discipline and the other disciplines that also showed in the data structure. Furthermore, a semantic difference of ontologies was found causing miscommunication and errors. These two cost control inhibiting factors are in direct confirmation with the research by Yang & Zhang (2006) where interoperability issues in a collaborative design environment are given such as a difference the terminologies or perspective of a design (semantic difference), or disparate systems and heterogeneous data sources (structural difference). These cost control inhibiting factors typically relate to a complex systems industry described by Winch (2003). In Al-Jibouri (2003), the tension field between collecting information and speeding up the process are described which also occurred in the case study. As stated before, the cost controllers want more and quicker information while the contractors don't want to have more administrative work. This results in a solution which is suboptimal for both parties.

In the research of Yu (2016) and Anumba, Pan, Issa, & Mutis (2008), it is stated that by applying the linked data method, the internet users can integrate physical world data and logical world data to do things such as drawing conclusions, creating business intelligence, enabling smart environments, supporting automated decision-making systems, etc. This is in confirmation with the result of the case study. From the interviewees, it was unanimous that their ideal cost control situation would be an active two-way connectivity between the financial data and the project information, such as work activities and products. With the use of this connectivity, they want to make dashboards on which the budgets would be compared to costs. All while the data is real-time linked to the activities and performances of the projects. Anumba, Pan, Issa, & Mutis (2008) describes the potential of semantic web technologies as 'to provide more timely responses to problems encountered in the field" and "provide an ontology that facilitates the sharing of design and construction information and the underlying semantics" (Anumba, Pan, Issa, & Mutis, 2008).

Using the linked data method in the scale model, data from different data structures was queried. This made it possible to continuously query data without the need to each time manually link the data from the different sources. The aim of the proof of concept was to provide evidence that linked data creates more and faster insight into the state of affairs with the same data regarding cost control in infrastructure projects. To test the proof of concept, two data structures were linked, that were not digitally linked before. It became possible to query both data structures in order to filter financial data based on project data and vice versa. From the case study, it became clear that for cost control currently this is done manually by searching through multiple (Excel) files which is a laborious task. It can thus be concluded that within the context of this case study, linked data creates faster insight into the state of affairs with the same data. This is in line with the research of Bus et al. (2018), who argues about the benefit of semantics for building automation regulation. Furthermore, these conclusions are in confirmation with the research of Niknam & Karshenas (2015) where they have constructed a similar proof of concept with the use of linked data. Niknam & Karshenas (2015), use the linked data method in order to automate the construction cost estimating approach and reduce human involvement in repetitive cost estimating activities. They conclude that their estimating application can substantially improve estimators efficiency.

Secondly, the proof of concept shows how data already present, can be transformed to meet the linked data principles and can directly be used by other applications. As the data is modular it can be reused easier than the original data. In the research by Atemezing, et al. (2011), it is argued that when data transformed to linked data, less time is required to develop applications. This is in line with the proof of concept data which required the making of a single XSLT file after which the data could be exported from Relatics to RDF/XML with a single action.

However, there are also drawbacks that need to be considered. When constructing the proof of concept, it became clear that the different applications require different computer languages. Although originally linked data was intended to be made using RDF/XML, soon other data formats such as RDF/TTL and RDF/JSON-LD were introduced as they are more human-friendly (Miličić, 2011).

Originally the proof of concept data was created using RDF/XML, however, in order to use the desired web application, data had to be transformed to RDF/TTL. Furthermore, when linking data sources for the first time, human intervention was often needed. In an ideal situation, objects would be described extensively, allowing programs to understand what the data means what other data is similar and should be linked to this object. However, this is often not the case and human intervention is needed to link objects together so that afterward programs understand that two objects should be linked together.

Lastly, the proof of concept showed that applying the linked data principles does not allow views of the data in all ways a company might want. For instance, the cost controllers wanted to have the work activities linked to the budget codes. Although it was possible in some cases, the budget codes and work activities mostly did not match due to a difference in level and demarcation.

Within the construction industry, both big data challenges and -opportunities arise that can also be seen in the case study. One of the challenges in the case study was a continuous tension field between the desire of the cost controllers to collect more data and the workload for contractors to measure and administrate that data was found. With the use of more data, cost controllers can make more precise analyses and allow the management to make more substantiated decisions. However, the cost controllers are also restrained by the growing amount of the time it takes to analyze the growing amount of data. This problem is also described by Whyte, Stasis, Lindkvist, & Lindkvist (2015) who state that within the construction industry new devices arise that generate, share and store data. Data from current IT systems such as ERP systems, planning, procurement, and design increases. An increasing flow of information is generated by people.

However, the big data problem previous mentioned also offers opportunities with the automation of data exchange, as can be seen in the research by (Martínez-Rojas, Marín, & Vila, 2016). In this research, it is shown how the decision-making process is improved by proper data handling, which results in contributing to successful project management. This is in direct line with the application of linked data to improve cost control. Programs can understand and interpret data, that is according to the linked data principles. This results in automation of data exchange and analysis, which can speed up the construction and decision-making processes, as shown in research by Bus et al. (2018) and Beach & Rezgui (2018).

The concept of automated data exchange can also be applied in cost control of projects where data is exchanged, analyzed and provided. Data according to the linked data principles, can be used by a width range of applications making it perfect, for example, to link 3D models with other project information. This is due to the RDF structure which causes big data quantities to become manageable chunks. Linked data has the potential to become a worldwide recognized standard as an unprecedented load of data is published on the web as linked data.

A lot of information of municipalities and ministries is already made online publicly available in linked data format (KOOP, 2018). The publicly available information is often quite valuable to contractors as it contains information on the project environments such as geodata and sewage data that is already available on the web (Luiten, 2017). As in construction projects, like the A1-A6 project, multiple companies collaborate with different semantics and syntax, a method like linked data could offer a solution to data exchange problems.

From both literature and research can be concluded that the application of linked data can lead to faster (and automated) information exchange, create possibilities to perform analyses on financial data quicker and more extensive, and it can give the possibility to view the data from different points of view. This leads to quicker information for the management so that they can react and make faster and more substantiated decisions. This could then lead to a project which is better in control and has fewer failure costs.

Within this research several limitations occurred that scoped the research. Although the research results of the case study matched with the literature, only a small number of interviews were held. This could give the risk of using data from interviews that are based on prejudices or biased. Furthermore, a single project was studied in which only the data exchange between two companies was examined, while in construction projects often a larger amount of collaborating parties are present and data exchange is even more complex. The proof of concept was made with the use of an online application which met the requirements of this research. However, it did not directly use data from different sources. Within the online application used, this option does exist. However, due to time and technical knowledge constraints, It was chosen not to use this option. Finally, it must be noted that this research investigated the possibilities of linked data for cost control in the construction industry and did not compare other methods with linked data such as data warehousing which is currently used at VolkerInfra.

6 Conclusion

At the beginning of this paper, it was argued that the application of linked data creates more and faster insight into the state of affairs with the same data regarding cost control in infrastructure projects. Evidence for this statement was provided using a literature study on linked data in the AEC industry, a case study on the financial processes during an infrastructure project, and the development of a proof of concept in which project data was recorded according to the linked data principles. The results from the case study showed that there was a clear gap in information exchange and linkage between the financial discipline and the other disciplines. This also showed from the data structure present in the case study. Furthermore, a semantic difference of ontologies between different disciplines and different companies was found causing miscommunication and errors.

From the interviewees, it was unanimous that their ideal cost control situation would be an active two-way connectivity between the financial data and the project information, such as work activities and products. With the use of this connectivity, they want to make dashboards on which the budgets would be compared to costs real-time linked to the activities and performances of the projects. Results from both literature and proof of concept showed that the application of linked data can reduce the actions taken when performing cost control. Furthermore, a larger and more diverse amount of data can be queried and analyzed at the same time as a query can be performed on multiple databases and data structures at the same time.

From both literature and research, it can be concluded that in the context of this research, the application of linked data can lead to more efficient (and automated) information exchange, creates the possibility to perform analyses on financial data quicker and more extensive, and it gives the possibility to view the data from different points of view. This is in confirmation with the hypothesis. Furthermore, as a result, this can lead to quicker and more information for the management so that they can make faster and more substantiated decisions. This then could lead to a project which is better in control and has fewer failure costs.

Recommendation for future research

In this research, three areas of future research have been found. Firstly it is strongly advised to research the application of linked data from the perspective of cost control in order to further demonstrate the added value of linked data for construction companies. In the AEC industry, multiple developments and research are taking place on linking geographical data to object information and libraries. However, the financial discipline is often not linked and no previous research was found on the application of linked data for cost control.

A second recommendation lies in the development of an ontology for the infrastructure industry. Currently, ontologies for the infrastructure industry are very limited which causes companies to develop their own ontologies. Due to these different ontologies, the ontologies miss their purpose of creating consistency in domain concepts.

The third recommendation for new research is to perform research on the practical implementation of linked data in the construction industry. Linked data is a difficult principle to understand and the implementation of linked data in the AEC is scarce. For the construction industry where people are not naturally educated in ICT technologies, a framework on how to implement linked data is needed.

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7 Appendixes

Appendix A. *Financial process design*

Appendix B. *Proof of concept queries*

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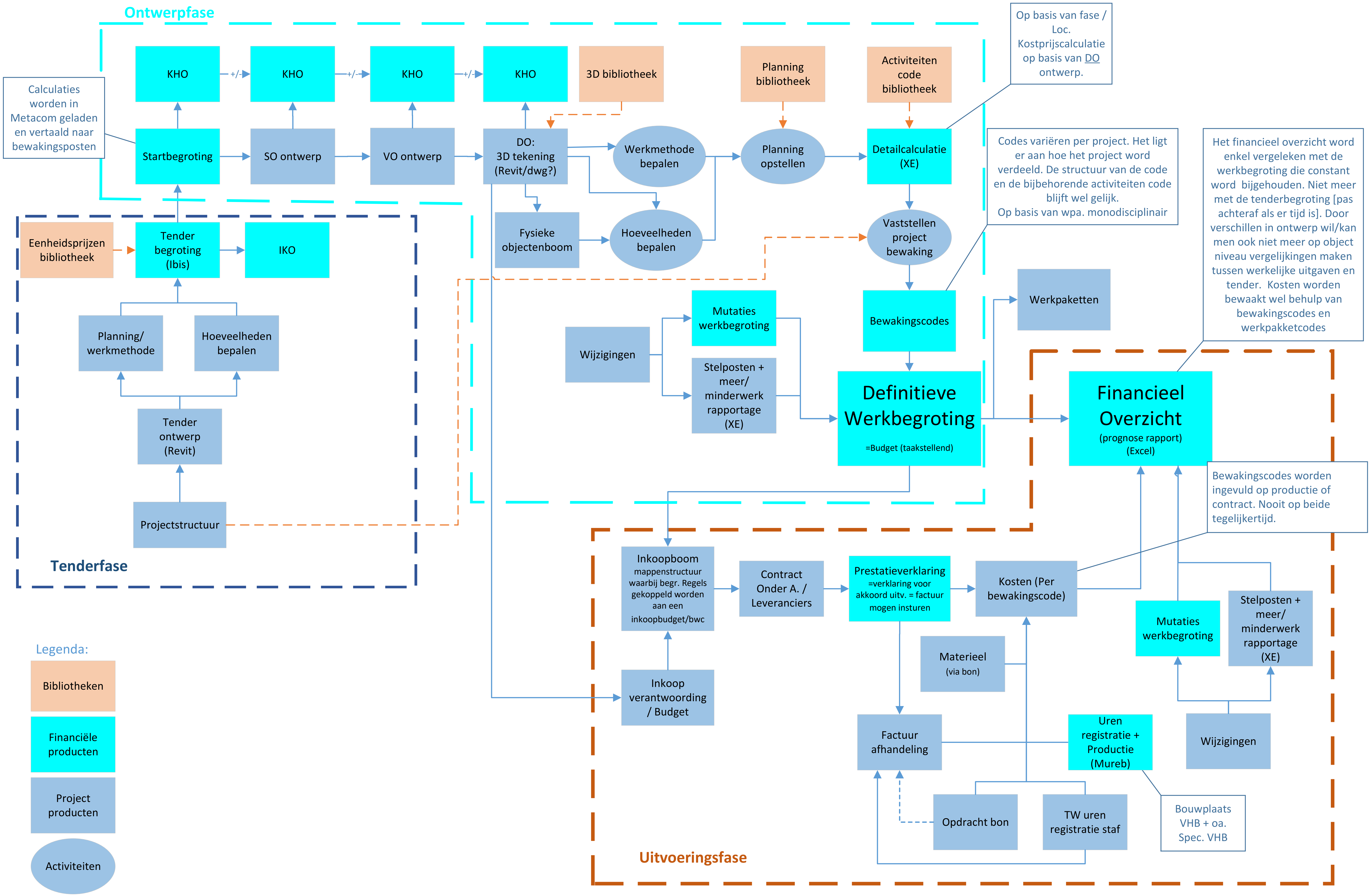
Appendix A: Financial cost control processes

Annex A

Financiële projectbewaking



Annex B: Proof of concept SPARQL-Query's

1. WP-00632 vervangen door werkpakket id:

```
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX owl: <http://www.w3.org/2002/07/owl#>
PREFIX vi: <https://vise.volkerinfra.nl/>

CONSTRUCT {
  vi:WP-00632 owl:has_Bewakingscode ?v .
  ?v rdfs:label ?label
}
WHERE {
  vi:WP-00632 owl:has_Bewakingscode ?v .
  OPTIONAL { ?v rdfs:label ?label }
}
```

2. P-00051 vervangen door product id van het hoogste niveau:

```
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX owl: <http://www.w3.org/2002/07/owl#>
PREFIX vi: <https://vise.volkerinfra.nl/>

CONSTRUCT {
   ?wp owl:has_Product vi:P-00051 .
  vi:P-00051 rdfs:label ?labelprod .
  ?wp rdfs:label ?label .
  ?wp owl:has_WPA ?wpa .
  ?wpa rdfs:label ?labelwpa .
  ?wp owl:has_Bewakingscode ?bwc .
  ?bwc rdfs:label ?labelbwc .
  ?bwc owl:has_budget ?budget .
  ?bwc owl:has_cost ?cost .
}
WHERE {
  ?wp owl:has_Product vi:P-00051 .
  OPTIONAL { vi:P-00051 rdfs:label ?labelprod .}
  OPTIONAL { ?wp rdfs:label ?label .}
```

```
  OPTIONAL { ?wp owl:has_WPA ?wpa .}
  OPTIONAL { ?wpa rdfs:label ?labelwpa .}
  OPTIONAL { ?wp owl:has_Bewakingscode ?bwc .}
  OPTIONAL { ?bwc rdfs:label ?labelbwc .}
  OPTIONAL { ?bwc owl:has_budget ?budget . FILTER(?budget != vi:0) .}
  OPTIONAL { ?bwc owl:has_cost ?cost . FILTER(?cost != vi:0) .}
}
```

3. P-00071 vervangen door product id -> Moet minimaal twee producten onder het werkpakket zitten:

```
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX owl: <http://www.w3.org/2002/07/owl#>
PREFIX vi: <https://vise.volkerinfra.nl/>

CONSTRUCT {
  vi:P-00071 rdfs:subclassof ?x .
  vi:P-00071 rdfs:label ?labelprod .
  ?x rdfs:subclassof ?p .
  ?x rdfs:label ?xlabel .
  ?p rdfs:label ?plabel .
  ?wp owl:has_Product ?p .
  ?wp rdfs:label ?wplabel .
  ?wp owl:has_WPA ?wpa .
  ?wpa rdfs:label ?wpalabel .
  ?wp owl:has_Bewakingscode ?bwc .
  ?bwc rdfs:label ?bwclabel .
  ?bwc owl:has_budget ?budget .
  ?bwc owl:has_cost ?cost .
}
WHERE {
  vi:P-00071 rdfs:subclassof ?x .
  OPTIONAL { vi:P-00071 rdfs:label ?labelprod . }
  ?x rdfs:subclassof* ?p .
  OPTIONAL { ?x rdfs:label ?xlabel . }
  OPTIONAL { ?p rdfs:label ?plabel . }
  ?wp owl:has_Product ?p .
```

```
  OPTIONAL { ?wp rdfs:label ?wplabel . }
  OPTIONAL { ?wp owl:has_WPA ?wpa .}
  OPTIONAL { ?wpa rdfs:label ?wpalabel . }
  OPTIONAL { ?wp owl:has_Bewakingscode ?bwc .}
  OPTIONAL { ?bwc rdfs:label ?bwclabel . }
  OPTIONAL { ?bwc owl:has_budget ?budget . FILTER(?budget != vi:0) .}
  OPTIONAL { ?bwc owl:has_cost ?cost . FILTER(?cost != vi:0) .}
}
```

4. WPA-03914 vervangen door WPA id:

```
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX owl: <http://www.w3.org/2002/07/owl#>
PREFIX vi: <https://vise.volkerinfra.nl/>

CONSTRUCT {
  ?wp owl:has_WPA vi:WPA-03914 .
  ?wp rdfs:label ?wplabel .
  vi:WPA-03914 rdfs:label ?wpalabel .
  ?wp owl:has_Bewakingscode ?bwc .
  ?bwc rdfs:label ?bwclabel .
  ?bwc owl:has_budget ?budget .
  ?bwc owl:has_cost ?cost .
}
WHERE {
  ?wp owl:has_WPA vi:WPA-03914 .
  OPTIONAL { ?wp rdfs:label ?wplabel .}
  OPTIONAL { vi:WPA-03914 rdfs:label ?wpalabel . }
  OPTIONAL { ?wp owl:has_Bewakingscode ?bwc .}
  OPTIONAL { ?bwc rdfs:label ?bwclabel .}
  OPTIONAL { ?bwc owl:has_budget ?budget . FILTER(?budget != vi:0) .}
  OPTIONAL { ?bwc owl:has_cost ?cost . FILTER(?cost != vi:0) .}
}
```