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Employing the model based systems engineering methodologies to develop a domain specific language for contracting of infrastructure projects

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Abstract
The procurement of infrastructure systems by the public sector is very costly, long and not transparent since the processes are based on preparing huge amounts of documents which are difficult to be kept consistent and to be used (e.g. bid evaluation). Acquisition architecture frameworks (AF) are metamodels, developed to model the whole enterprise/system life cycle stages including system procurement. Our previous study analyzed the currently used AFs such as DoDAF, MoDAF and TRAK to assess their adequacy and efficiency in modelling the infrastructure projects. The results showed that many of the procurement related concerns are overlooked such as financial matters e.g. cost and revenue calculation; and risk management aspects e.g. risk calculation and risk allocation. This paper focuses on identifying the procurement concerns and adding new viewpoints to the architecture frameworks; and developing a domain specific language based on SysML to model the new viewpoints. A methodology is provided which shows how the metamodel (abstract syntax) and the language stereotypes (concrete syntax) are developed. The results firstly show the 18 identified viewpoints of procurement domain and then one of them (project funding) is chosen to be described in this paper. The conceptual definition of the 'project funding' viewpoint and the models it generates are illustrated as example diagrams of this DSL. This DSL can be used by the domain practitioners, who are the contracting officers and procurement managers, to generate the contracting materials to facilitate the contracting process, assure the consistency of the procurement documents, giving better project outcomes.

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***Abstract*— The procurement of infrastructure systems by the public sector is very costly, long and not transparent since the processes are based on preparing huge amounts of documents which are difficult to be kept consistent and to be used (e.g. bid evaluation). Acquisition architecture frameworks (AF) are metamodels, developed to model the whole enterprise/system life cycle stages including system procurement. Our previous study analyzed the currently used AFs such as DoDAF, MoDAF and TRAK to assess their adequacy and efficiency in modelling the infrastructure projects. The results showed that many of the procurement related concerns are overlooked such as financial matters e.g. cost and revenue calculation; and risk management aspects e.g. risk calculation and risk allocation. This paper focuses on identifying the procurement concerns and adding new viewpoints to the architecture frameworks; and developing a domain specific language based on SysML to model the new viewpoints. A methodology is provided which shows how the metamodel (abstract syntax) and the language stereotypes (concrete syntax) are developed. The results firstly show the 18 identified viewpoints of procurement domain and then one of them (project funding) is chosen to be described in this paper. The conceptual definition of the 'project funding' viewpoint and the models it generates are illustrated as example diagrams of this DSL. This DSL can be used by the domain practitioners, who are the contracting officers and procurement managers, to generate the contracting materials to facilitate the contracting process, assure the consistency of the procurement documents, giving better project outcomes.**

Keywords—Domain Specific Modelling Language; Infrastructure procurement; Model Based Systems Engineering; System Modelling

I. INTRODUCTION

A. Problem Statement

Infrastructure typically characterizes technical structures such as transport systems (roads, bridges, tunnels, etc.), water supply, sewers, electrical grids, telecommunications, and so forth [1], and can be defined as the physical components of interrelated systems providing commodities and services essential to enable, sustain, or enhance societal living conditions [2]. Therefore infrastructure is inherently a set of interrelated systems, also known as a system of systems (SoS). Projects defined to acquire such systems are costly, long and complex to manage. The acquisition domain is a complex system of organizations with different cultures and concerns, and which carries out different activities. However, they all have a common goal: to develop a system that meets their requirements, addresses their interests, and brings them value. So it is worth to differentiate the concerns related to the system with the ones that are focused on the 'procurement of' the system. System related concerns include the safety, security, performance and functionality of the system; while the procurement related concerns include project costs, project risks, responsibility of the contract sides, and project scheduling, etc.

Governments publish the rules of procurements in various documents to regulate the procurement context. Despite the completeness and expressiveness of the procurement guideline documents, which are written in natural languages, there exist many problems regarding understanding, interpreting and consistent application of these rules. Moreover, responding to the "Request for Proposals" issued by governments involves generating a large amount of documents by bidders which introduces complexity and costs to the bidding, bid evaluation and negotiation processes. Local governments often lack the staff needed to plan, negotiate and monitor a contract that is suited to local circumstances and must spend significant resources acquiring the expertise and advice required. A 2007 report from the UK National Audit Office [3] found that the average cost of external advice in procuring Private Finance Initiative deals was just over £3 million per project.

B. Related Works

Many approaches have been used to tackle these problems; one group of approaches are the document based frameworks, best practices and reference guides published by academia [4, 5] and expert PPP agencies [6]. Another approach are toolkits, such as The European PPP Expertise Centre (EPEC) Toolkit [7], Public Private Infrastructure Advisory Facility (PPIAF) Toolkit [8], World Bank and AusAID Toolkit developed for the Indian Ministry of Finance [9], and the Asian Development Bank Toolkits [10, 11]. These toolkits are more structured documents held in web pages and excel files, and which are designed to help calculate the financial aspects of a project.

Although these approaches are helpful via summarizing and simplifying the regulations, they cannot assure that consistent and complete procurement documents will be generated.

C. Outline

Considering the inefficiencies of the mentioned procurement management methods, in this study we employ the Model Based Systems Engineering (MBSE) methodologies and tools to address the problems raised from document centric engineering. So, this paper focuses on developing a domain specific language based on SysML to model the infrastructure procurement projects. The main fundamentals of MBSE and the proposed solution are explained in section 2. Section 3 briefly describes the methodology used for creating the metamodel and the language. Some samples of the achieved results are provided in section 4. The application of the language is demonstrated in section 5 by modelling the funding structure of a real project. Finally, section 6 draws the paper conclusion.

II. PROPOSED SOLUTION

MBSE "is the formalized application of modelling to support system requirements, design, analysis, verification, and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases" [12]. MBSE is intended to facilitate systems engineering activities that have traditionally been performed using the document-based approach and result in enhanced communications. According to the studies on MBSE since 2006 [13] [14] [15] [16] [17], practicing MBSE involves six fundamentals: Process Standard, Systems Engineering Method, Architecture Framework (AF), Architecture Description Language (ADL), Model and data exchange standard, and modelling tool.

The Architecture Frameworks that are discussed in this paper are the acquisition oriented AFs. The acquisition AFs are developed by the defense sectors in the form of metamodels to provide a standardized knowledge structure for information sharing. These metamodels generate the consistent and integrated models of both the '*system'* and the '*acquisition project*' defined to acquire the system. DoDAF (Department of Defense Architecture Framework) is an example of acquisition AF. UML (Unified Modelling Language) and SysML (Systems Modelling Language; a UML profile) are the ADLs often used to model AF artefacts.

Our previous studies [18] [19] have analyzed the Architecture Frameworks to assess their adequacy and effectiveness in modelling the acquisition projects. The results show that the system specific concerns such as user requirements, system services, physical and functional aspects of the system are fully or partially covered by the current architecture frameworks (DoDAF, MoDAF, TRAK). However, the concerns related to the '*procurement of* the system' such as financial aspects of the project, project risks, bid evaluation and asset ownership are mainly overlooked. So, the next step of this research, which is summarized in this paper, focuses on expanding the architecture frameworks to make them capable of covering all aspects of the procurement projects. Since this expansion should be integrated to all the AFs, we have picked UPDM [20] (Unified Profile for DoDAF and MoDAF) as the internationally accepted and academically registered profile for the mentioned AFs.

In order to extend the Project/Acquisition viewpoints of UPDM, three enhancements will be made: identifying the views to depict common information needed for procurement, an expansion of the metamodel to the procurement domain, and finally the language necessary to populate these views. Fig. 1 illustrates how this DSL fits into the context of current literature. As shown, UPDM consists of a metamodel (abstract syntax) which is mapped to a profile (concrete syntax). The UPDM profile is a group of stereotypes which are specializations of UML and SysML. Likewise, the DSL has a metamodel that expands the UPDM metamodel (adds new concepts to it); and is mapped to a profile which is specializations of (i.e. extends) SysML. This paper focuses on identifying the procurement concerns and adding new viewpoints to the architecture frameworks; and developing a domain specific language based on SysML to be served as the ADL to model the new viewpoints.

III. METHODOLOGY

In order to design and implement the DSL, a customized method is created by combining the methods adopted from other studies. The first phase of the method is developing the metamodel of the DSL (abstract syntax) is adopted from the studies that have discussed the metamodel development and validations including [21], [22], [23] and [16]. The second phase is implementation of the language (concrete syntax) which is based on the methods borrowed from following studies: [24], [25] and [26]. The metamodel development phase is comprised of a set of steps which are described below:

- **Knowledge gathering**: collecting the information sources to be used as the knowledge base for extracting the domain concepts.

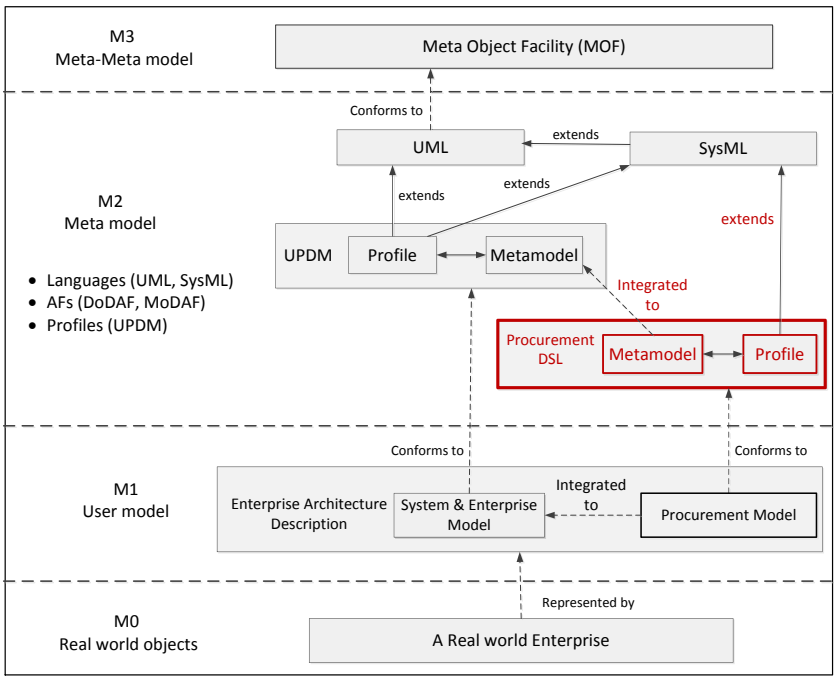

Fig. 1. Putting the research deliverable into the context of existing literature

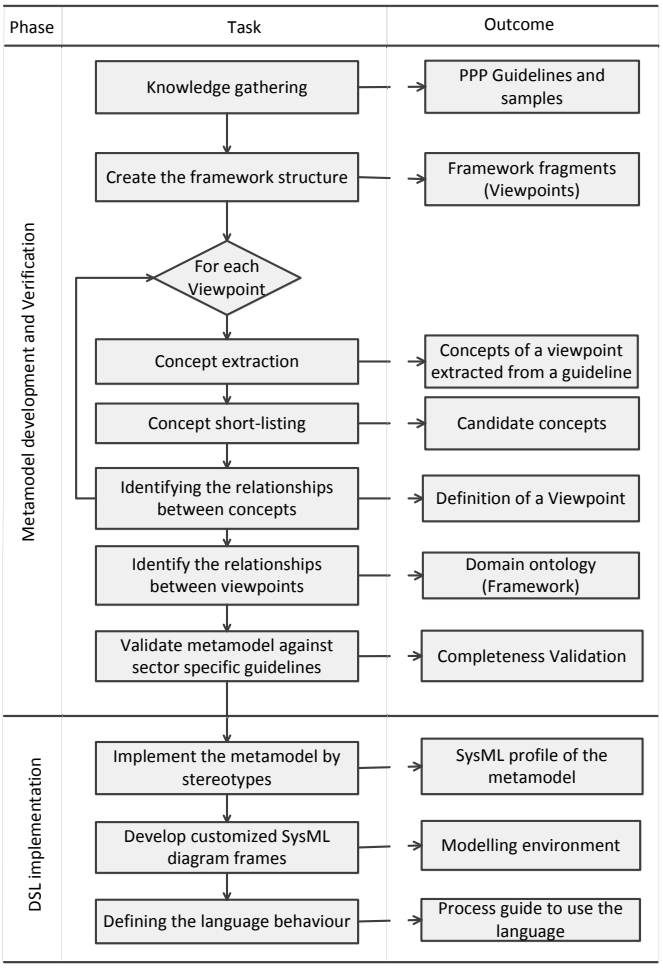

Fig. 2. Method of developing the Metamodel and the Language

- **Creating the metamodel (framework) structure**: the domain will be broken into areas of concerns also known as viewpoints. It allows us to develop each viewpoint separately which is simpler than developing the whole metamodel at once.
- **Concept extraction**: once the viewpoints are identified, the corresponding parts of the gathered knowledge are explored to identify the concepts that can be used for defining that part of the domain (viewpoint).
- **Concept shortlisting**: the gathered concepts from different resources need to be shortlisted to a finalized list of concepts for each viewpoint. The shortlisting is mainly done based on the occurrence of a concept in different resources.
- **Relationships between the concepts**: the concepts gathered for each viewpoint need to be related to each other to create the meaningful tuples. The combination of these tuples forms the body of a viewpoint.
- **Relationships between the viewpoints**: after creating each viewpoint, they also need to be related to each other so they will form the domain metamodel (framework).
- **Metamodel validation**: the created metamodel needs to be validated against the domain knowledge. So a set of information which is not used in the development process is used here to validate the completeness and accuracy of the metamodel.

The domain metamodel created in phase 1 needs to be mapped to a concrete syntax, so the users can interact with the language. Phase 2 of the method develops the concrete syntax as a SysML profile (a profile is comprised of customized stereotypes that are mapped to the domain semantics). The steps of phase 2 are as following:

- **Implementing the metamodel by stereotypes:** each concept of the metamodel is concretized in a stereotype that is a specialized version of a class (or a block in SysML).
- **Developing customized SysML diagrams:** the stereotypes are categorized based on the viewpoint they belong to; so each group of them create a new customized diagram type that can be used for modelling a part of the domain (viewpoint).
- **Defining the language behavior:** the right orders of using the diagrams and the suggested steps for modelling are developed and provided to the users so it guides them through application of the language and modelling process.

IV. RESULTS

In this section the preliminary results of each step are provided as a sample to help understanding of how the method works.

A. Knowledge gathering

In this step, the procurement frameworks and guidelines were collected from the infrastructure departments and regulatory agencies of a variety of countries including Australia, UK, South Africa, India, Hong Kong and Singapore. Some of the main knowledge sources are as follows:

- Public-Private Partnerships Reference Guide, Version 2.0 [27]
- How to Engage with the Private Sector in Public-Private Partnerships in Emerging Markets [28]
- Concessions for infrastructure - A guide to their design and award [29]
- Government Guarantees - Allocating and Valuing Risk in Privately Financed Infrastructure Projects [30]

B. Metamodel structure (identified viewpoints)

In this step the structure of procurement domain is created according to the gathered knowledge. So the most frequent sections of these guidelines are picked and structured to form the structure of infrastructure procurement process. As shown in Fig. 3, this process has 6 stages and each stage consists of some parts or viewpoints (18 viewpoints). For instance, the 'Project Funding' viewpoint is about finance sources of the project and generally addresses the concerns of project financiers such as the lenders and shareholders. As another example 'Value for Money' viewpoint generates an analysis model which help both sides of the contract to assess whether the project is justified in terms of generating cash flow.

C. Concept extraction

The construction blocks of the viewpoints are concepts, so in order to develop the viewpoints their constructing concepts should be extracted from the knowledge sources. So, in this

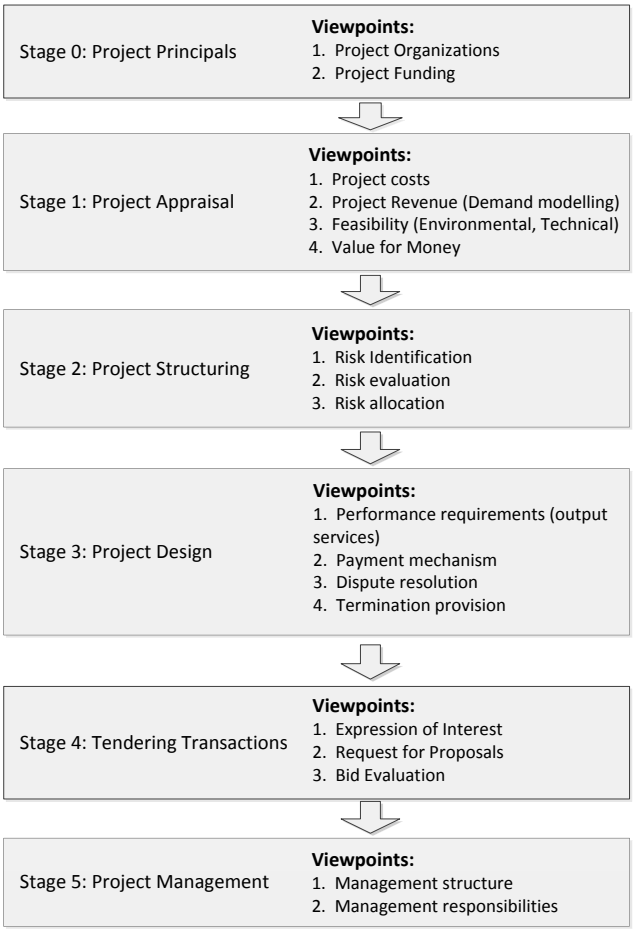

Fig. 3. The breakdown structure of the infrastructure procurement domain

step the concepts are manually extracted from the sources which are mainly text base. TABLE I is an example of a concept extraction table which contains the concepts of project funding extracted from two different sources. As shown, despite differences between the information of various sources, there are many commonalities between them.

D. Concept shortlisting

The concepts that are more frequently occurred in different sources are selected as the finalized list of concepts for that viewpoint. The list of concepts for 'Project Funding' viewpoint is as follows: ProjectFinance; Finance; Financier; CostOfFinance; Cost; Lender; Debt; Shareholder; Equity; CostOfDebt; ReturnOnEquity; InterestRate.

E. concept relationships

As shown in TABLE I the concepts are extracted as the tuples, so the relationships between the concepts are identified in step section *C*.

F. The relationships between viewpoints

After creating the viewpoints, they need to be linked together. The relationships among the viewpoints are kept via the relationship between their concepts. In the other words, there are concepts that are shared by different viewpoints so they link the viewpoints. For example, the concept 'Financier' appears in both 'Project Organizations' and 'Project Funding' viewpoints; or, the 'CostOfFinance' is shared between the 'Project Funding' and 'Feasibility' viewpoints.

TABLE I. Extracted concepts for the 'project funding' viewpoint

Source	Extracted Concepts: Project Funding
World Bank: Public-Private Partnerships Reference Guide, Version 2.0 (p 50)	Project finance has part: (Debt, Equity) Project Cost -- covered by -- Debt + Equity Lender -- provides -- debt debt -- has -- interest rate Shareholder (equity investor) provides -- equity equity -- has -- return rate to decrease the financial costs: Shareholder --- *corporate guarantee* --- lenders Government --- *corporate guarantee* --- debt (lenders) *Government --- provide finance (as lender) --- SPV*
How to Engage with the Private Sector in Public-Private Partnerships in Emerging Markets (p 53)	Private sector Finance -- consists of -- Equity -- provided by -- investors third-party debt -- provided by -- banks *financial instruments* (e.g. *bonds*) Lender -- provides -- *corporate finance* -- to -- Engineering contractor

G. Validation of the metamodel

As mentioned earlier, some of the sources are used for metamodel development and some others are reserved for metamodel validation. In this step the created metamodel is compared against the concepts extracted from the validation sources to assure the completeness of the metamodel. For example, the 'Project Funding' viewpoint is compared against two other guidelines and some concepts are added to it as they were used in the two validation sources but didn't exist in the created viewpoint. The added concepts are: WeightedAverageCostOfCapital; CorporateFinance; CorporateGuarantee; FinancierDegreeOfCommitment.

H. Implementation of the SysML profile

The previous steps have developed the metamodel of the procurement domain; this metamodel is served as the abstract syntax of the language. In order to make this metamodel accessible by the users (modelers) it needs to be implemented in a tool. So, the metamodel is implemented as a SysML profile in a modelling tool. So, each concept of the metamodel is represented by a stereotype. Fig. 4 shows the stereotypes created for definition of the 'Project Funding' viewpoint.

I. Developing the SysML customized diagram frames

The created stereotypes need to be provided to the modeler in a diagram pane, so they can use these stereotypes (which are predefined meta-classes) to define their own classes according to the specific project that is being modeled. A diagram pane can be seen in Fig. 4 as an example.

J. Defining the language behavior

The right order of using the language diagrams and the steps of modelling process should be provided to the users as a guide for using this new modelling language.

V. APPLICATION OF THE LANGUAGE

In this section a project is used as a case study to show how the language can model a real project. In this case study the funding structure of the project is modeled as an example.

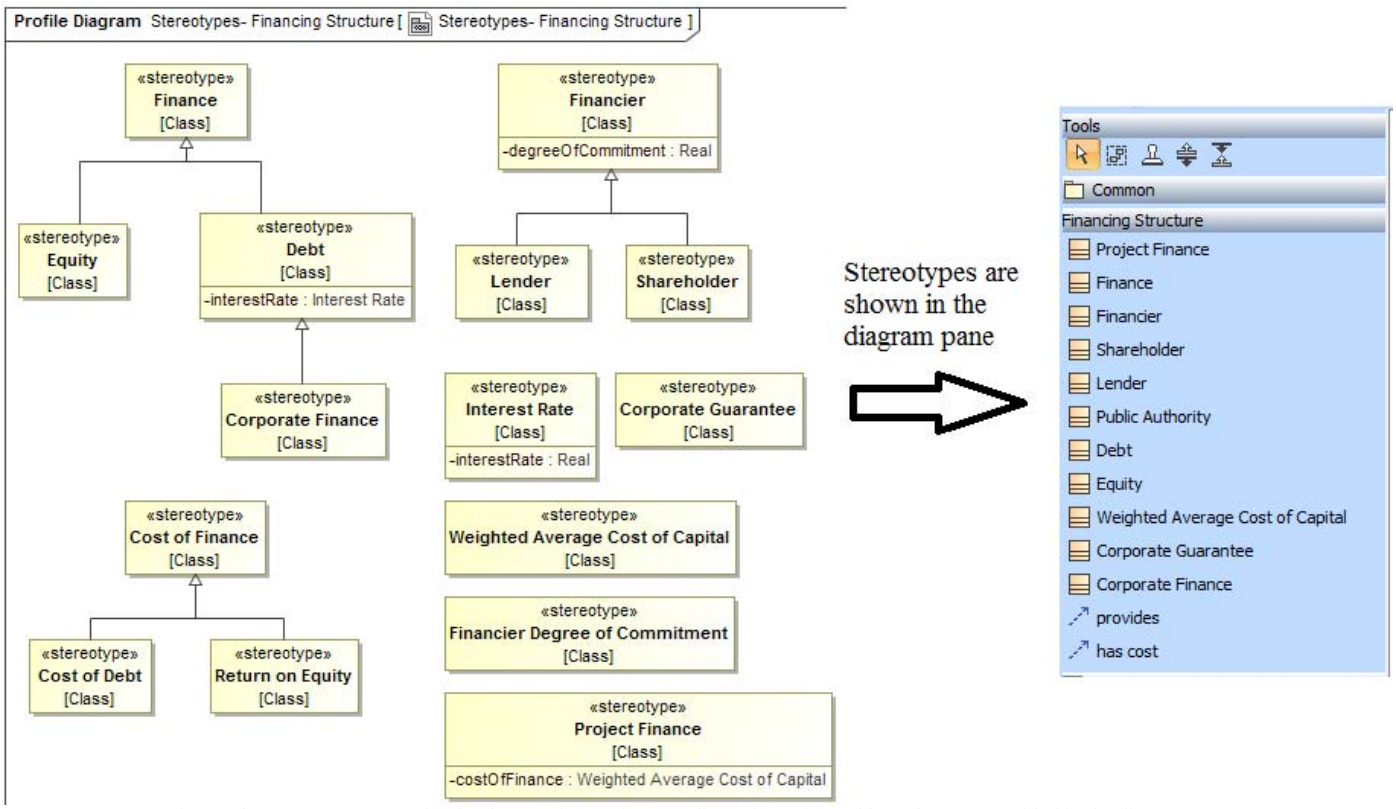

Fig. 4. The stereotypes created to implement the 'Project Funding' viewpoint and how they are provided in the diagram pane

Transferring responsibility to the private sector for mobilizing finance for infrastructure investment is one of the major aspects of infrastructure procurement. While helpful for raising finance for large and highly leveraged investments, project finance comes at a cost because interest rates for project-finance debt are more expensive than government borrowing, and are often more expensive than borrowing by established companies. The aim of project shareholders and their advisors in developing the finance structure is typically to minimize the cost of finance for the project. Because equity is more expensive than debt, project shareholders use a high proportion of debt to finance the project.

In order to model the funding structure of a project, a rail project conducted by the NSW Rail Corporation is chosen. As the financing viewpoint shows, there are two main sources of finance to cover the project costs: debt provided by lenders and equity provided by shareholders. Both sources incur costs to the project because the debt plus interest must be paid back and equity will be collected by the shareholders plus a return on their investment (return on equity). The Financing sources for the RailCorp Rolling Stock PPP Project [31], as shown in Fig. 5, are used to demonstrate this viewpoint. Fig. 7 shows how the Financing Structure diagram of the language models the project finances. A financing table, as shown in Fig. 6, is then automatically created based on the finance structure diagram; the numbers are not real, they are for demonstration only.

Fig. 5. Sources of Finance in RailCorp rolling stock PPP Project

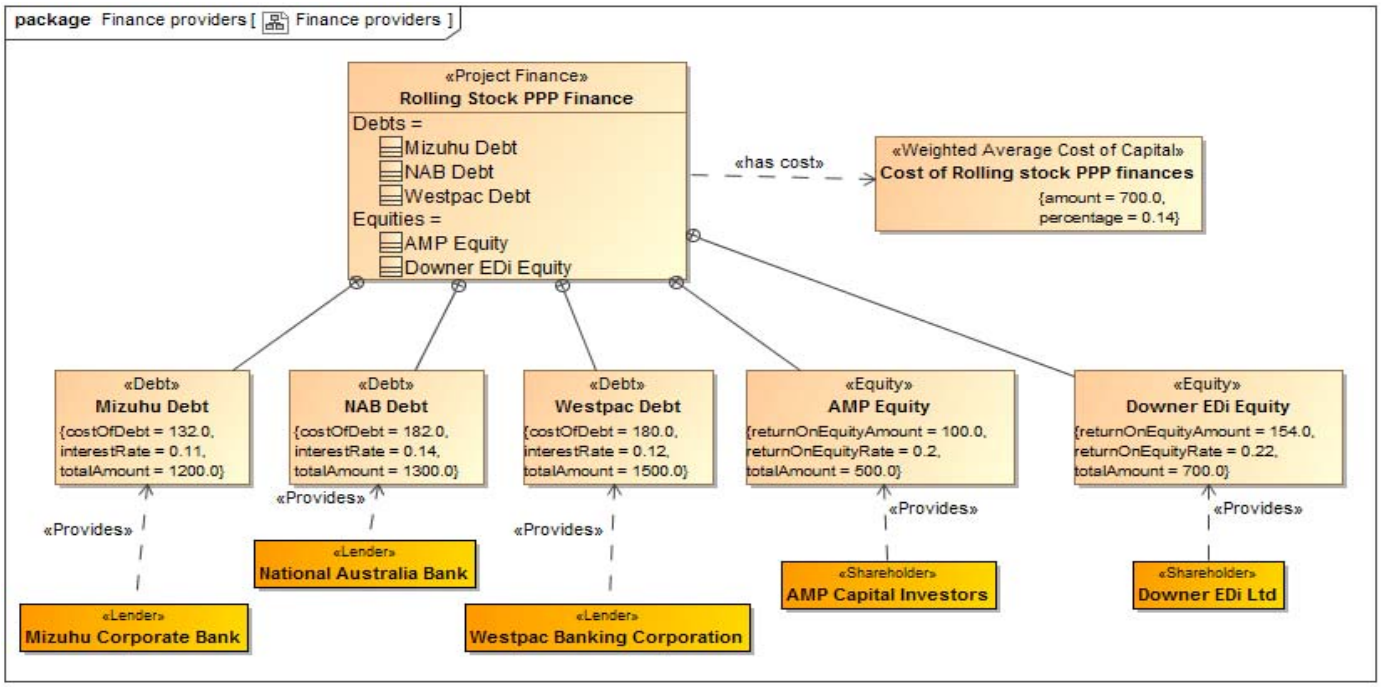

Fig. 7. Finance Structure diagram models the finance sources and their providing financiers

Criteria

Element Type: Finance ... Scope (optional): A - Financing Structure

#	Name	Providing Financier	Total Amount	Interest Rate	Cost Of Debt	Return On Equity Rate	Return On Equity Amount
1	AMP Equity	AMP Capital Investors	500.0			0.2	100.0
2	Downer EDi Equity	Downer EDi Ltd	700.0			0.22	154.0
3	Mizuhu Debt	Mizuhu Corporate Bank	1200.0	0.11	132.0		
4	NAB Debt	National Australia Bank	1300.0	0.14	182.0		
5	Westpac Debt	Westpac Banking Corporation	1500.0	0.12	180.0		

Fig. 6. Finance table, automatically created by the language

VI. CONCLUSION

This paper throws a light on the gap that exists in existing architecture frameworks as they do not sufficiently cover the procurement process of the complex systems. So this paper suggests a method for improving the Architecture Frameworks to increase their capability in modelling the procurement projects of infrastructure systems. The solution is proposed as a Domain Specific Language which is customized for procurement of infrastructure projects. The methodology for development and implementation of this language is designed by adopting other relevant methods. The methodology shows how the metamodel (abstract syntax) and the language stereotypes (concrete syntax) are developed. The results firstly introduce the 18 identified viewpoints of procurement domain and then the 'Project Funding' viewpoint is chosen as an example to show the process of its development and its application. In the next step of this study, all other viewpoints will be created to provide a full modelling language for infrastructure procurement. This DSL can be used by the domain practitioners, who are the contracting officers and procurement managers, to generate the contracting materials to facilitate the contracting process, assure the consistency of the procurement documents, giving better project outcomes.

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