

Visualizing Software Models

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Abstract

Software development is a complex and difficult task that requires the investment of significant resources and carries major risks. Model driven development approaches can help these tasks, but they generate thousands of objects and relationships which are difficult to analyse without losing the context, and mostly by proprietary tools. We propose a visualizer for the data model of these applications/information systems that makes use of visualization techniques with the proper filters to allow a user to navigate between objects and abstraction levels without losing the context and/or focus. We used the Design Science Research Methodology to conduct our research. This proposal was demonstrated in a real life company that uses a tool with model-driven-development concepts to develop Information Systems and it helped to identify the objects with higher importance in the evaluated applications. We evaluated it with feedback gathered from interviews and results from the application of the visualizer in real applications. The artifacts usability was also measured through user tests and it has shown that it has a nice usability.

Keywords: MDD, visualization, models, rapid development tools, visualization techniques, abstraction

Resumo

O desenvolvimento de software é uma tarefa difícil e complexa que requer um investimento significativo de recursos e que contém muitos riscos. O desenvolvimento de software orientado a modelos pode ajudar nestas tarefas, mas são gerados milhares de objectos e relações que são difíceis de analisar sem perder o contexto e, maioritariamente, através de ferramentas proprietárias. Propomos, então, um visualizador para o modelo de dados das definições destas aplicações/sistemas de informação que faz uso de técnicas de visualização com os filtros adequados de forma a permitir ao utilizador navegar entre objectos e níveis de abstracção sem perder o contexto e/ou o foco. Utilizamos a metodologia *Design Science Research* para conduzir a nossa investigação. Esta proposta foi demonstrada numa empresa real que utiliza uma ferramenta que tira partido dos conceitos de desenvolvimento de software orientado a modelos para desenvolver sistemas de informação, e ajudou a identificar os objectos mais importantes nas aplicações avaliadas. Avaliámos a nossa proposta com *feedback* recolhido através de entrevistas e de resultados obtidos através do uso do visualizador em aplicações reais. Também medimos a usabilidade do artefacto desenvolvido através de testes com utilizadores, o que mostrou que possui uma boa usabilidade.

Palavras-Chave: Desenvolvimento orientado a modelos, visualização, ferramentas de desenvolvimento rápido, técnicas de visualização, abstracção

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List of Acronyms

MDD	Model-driven development
MDA	Model-driven architecture
MDE	Model-driven engineering
DSRM	Design Science Research Methodology
PIM	Platform independent model
PSM	Platform specific model
FSM	FirstSightModel

1. Introduction

Software development is a complex and difficult task that requires the investment of significant resources and carries major risks. According to its proponents, model-driven software development approaches are improving the way we build software [1]. The software developed through these approaches generates a large amount of modules and database entries, with hundreds of tables which have around 100.000 different attributes.

The field of visualization is getting mature and the visualization of data models can make possible to researchers, analysts and engineers to get an insight of this data model in an effective and efficient way [2].

One way to make the analysis of such complex model instances is to go through the visualization of these data models in different abstraction levels with the capacity of navigating through them.

Our proposal consists in a set of state-of-the-art visual representations, like graphics, combined in a tool for visualization that will allow the user to navigate through data models raising or lowering the level of abstraction according to their needs. This proposal was tested through its addition to an existing Rapid Development tool, Genio, and it helped to identify the objects with higher importance in the evaluated applications and gave the users a more simple way to analyse the dependencies in the application's definitions.

We tested with several users, and evaluated the chosen visualization techniques through observation and interviews/surveys and performed a critic analysis between them. In the evaluation, we focused on the data model analysis and reasoning in order to guarantee that the visualizations used are, in fact, helpful to visualize the relationships between objects in the data models of these applications generated automatically through the definition of the models and from the MDD approach. We also focused in the usability of our artefact.

The structure of this document is influenced by the research methodology followed to conduct this research, Design Science Research Methodology (DSRM). So, to follow the steps defined in the DSRM, we structured this document based on its steps. Next, we present the research methodology and a detailed structure of this document in presented in section 1.2.

1.1. Research Methodology

The methodology applied in the development of this thesis is Design Science Research (DSR). DSR is a system of principles, practices and procedures required to carry out a study [3].

DSR methodology has the objective of surpassing research paradigms, such as the traditional descriptive research and interpretative research [3]. To achieve this goal DSRM has its roots in

engineering and seeks to create and evaluate “IT artifacts intended to solve identified organizational problems” [3].

To overcome these organizational problems, DSRM proposes the creation and evaluation of artifacts that may include constructs (vocabulary and symbols), models (abstractions and representations), methods (algorithms and practices) and instantiations (implemented and prototype systems).

The DSRM process includes six steps [3]: problem identification and motivation, definition of the objectives for a solution, design and development, demonstration, evaluation, and communication. Next, we’ll explain each of those steps:

- **Problem identification and motivation:** Consist on defining the specific research problem and justifying the value of a solution. The problem should be atomized conceptually so that the solution can capture its complexity. The problem definition will be used to develop an artifact to effectively provide a solution to the proposed problem.
- **Definition of the objectives for a solution:** In this step we infer the objectives of a solution from the problem definition and knowledge of what is possible and feasible considering the related work analysis and discussion. Objectives can be quantitative, e.g., terms in which a desirable solution would be better than current ones, or qualitative, e.g., a description of how a new artifact is expected to support solutions to problems not previously addressed. Given that design is an incremental process, not all problems become objectives since a solution may only intend to partially solve them.
- **Design and development:** In this step we create the artifact. It can be any designed object in which a research contribution is embedded in the design. This activity includes determining the artifact’s desired functionality and its architecture and then creating the actual artifact. Resources required for moving from objectives to design and development include knowledge of theory that can be brought to bear in a solution
- **Demonstration:** In this iteration we demonstrate the use of the artifact to solve one or more instances of the problem. This demonstration can be done through simulation, experimentation or case studies. It should be explicit how to use the artifact to solve the problem.
- **Evaluation:** In this step we’ll assess (through observation and measurements) how well the artifact supports a solution to the problem. This activity involves comparing the objectives of a solution to actual observed results from use of the artifact in the demonstration. It requires knowledge of relevant metrics and analysis techniques.
- **Communication:** In this last step we’ll communicate the problem and its importance, the artifact, its utility and novelty, the rigor of its design, and its effectiveness to researchers and other relevant audiences such as practicing professionals, when appropriate.

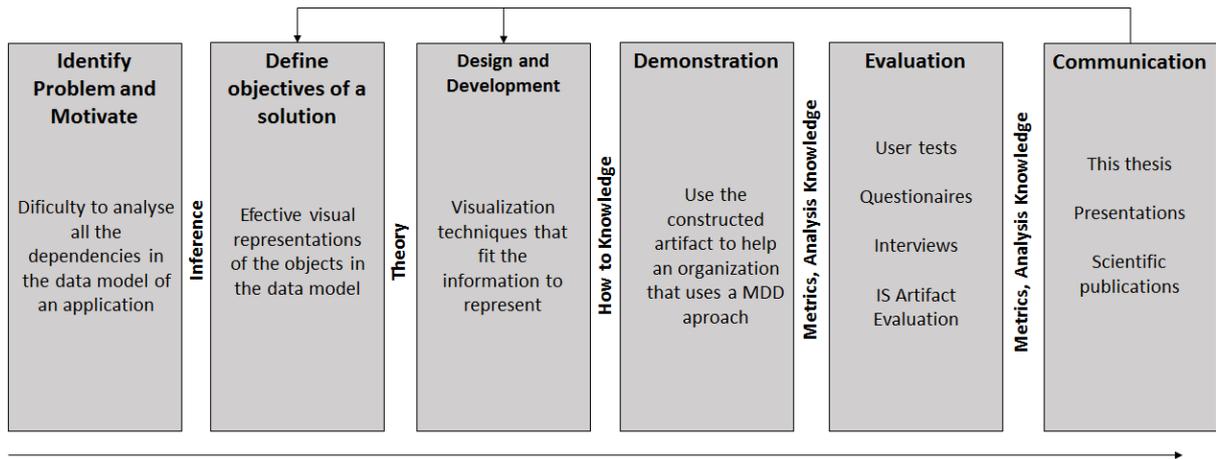


Fig. 1. - The DSRM process (adapted from [3])

As shown in Fig. 1, we adapted the DSRM process to our research and we'll explain each step of it in the next sections.

1.2. Structure of the document

As we already noted, the structure of this document is influenced by the methodology followed to conduct this research, DSRM. So, to represent the steps defined in it, this document is structured as displayed in Table 1:

Chapter	Description
2.Research Problem	Description of the research problem identified and its motivation
3.Related Work	Review of the topics related to the problem, including a critical analysis of existing solutions
4.Objectives	Identified objectives of a solution
5.Research Proposal	Extensive description of the research proposal
6.Demonstration	Establishment of the use of our proposal in order to solve an instance of the problem
7.Evaluation	Evaluation of how our proposal solves the problem by achieving the objectives defined
8.Conclusion	Final conclusions, lessons learned, communication, limitations and future work

Table 1 - Thesis outline

2. Research Problem

This chapter describes the "Identify problem & motivate" step of the DSRM process, where we become aware and recognize a problem from a state of the art review, giving us the issues that must be addressed.

The growing adoption of Model-Driven Development (MDD) [4] [5] methods, where models are the primary artifact of the development process, is shifting the focus of existing software engineering methods from code to models. In this context, the correctness of such models plays an important role in the quality of the final software system. Unfortunately, there are currently few tools that support the verification of software models [6].

MDD of applications brings many advantages concerning the development of highly complex information systems, which can be seen in development time, software quality, team's knowledge management, maintenance and evolution of the system, among others.

However, the state-of-the-art of models with the capacity of automatically generating systems are a mixture of technological concepts that are better understood by programmers.

Effective performance of many software engineering tasks requires knowledge of how the system works. Gaining the desired knowledge by studying or statically analysing the source code can be difficult [7].

The produced models from rapid development tools that use the MDD concept make a difficult task for people with no programming skills to be able to understand them.

Software artifacts in industrial applications can consist of thousands of code files, making difficult to manage and analyse the system's complexity. Moreover, in complex systems, the number of models' instances that describe, say, a full ERP, have around 100.000 different attributes.

It is important that analysts and developers can extract the most relevant objects of a system from complex models and navigate through the model.

There are also more challenges related to the use of MDD [8]:

- Understanding and managing the interrelations among the multiple representations of software development artifacts representing different views or levels of abstraction of the same concept;
- Comparing and merging different versions of models, e.g., visualizing the differences in a usable way.

Given the complexity of these applications, the reuse of models to integrate with other ones can be a challenging task because of the many direct and implicit relations between them.

3. Related Work

In this chapter we present a literary review of the topics related to the problem. We start by introducing the most important concepts referred in this document, followed by the analysis of the tools that make used of these concepts, with more focus on the way they visually represent their objects.

Subsequently, we'll introduce a taxonomy of visualization techniques from which we have chosen the right ones for our proposal.

3.1. Model-Driven Engineering

Model driven engineering (MDE) combines process and analysis with architecture [7].

In MDE, models are the prime artifacts, and developing high-quality systems depends on developing high-quality models and performing transformations that preserve quality or even improve it [8].

In Figure 2, we present our view of the MDE scope.

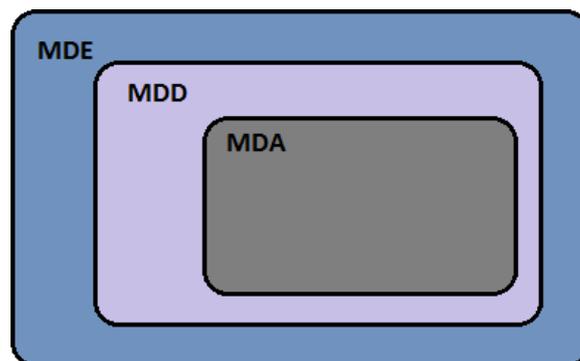


Fig. 2. - Overview of the MDE related concepts

As seen in Figure 2, MDE can be viewed as a superset of Model Driven Development (MDD), which can be a superset of Model Driven Architecture (MDA).

MDD can be mistaken for MDE because the principles are the same, but MDE goes beyond of the pure development activities and encompasses other model-based tasks of a complete software engineering process (e.g. the model-based evolution of the system).

We'll explain the concepts behind MDD and MDA, focusing more in the first one.

3.1.1. Model-Driven Development

Model-driven development is simply the notion that we can construct a model of a system that we can then transform into the real thing [9].

It is a software-engineering approach consisting in the application of models and model technologies to raise the level of abstraction at which developers create and evolve software, with the goal of both simplifying and formalizing (standardizing, so that automation is possible) the various activities and tasks that comprise the software development life cycle [10] .

Models consist of sets of elements that describe some physical, abstract, or hypothetical reality [11]. Good models serve as means of communication; they're cheaper to build than the real thing and they can be transformed into an implementation.

Central to MDD (and Model Driven Architectures) is the notion of creating different models at different levels of abstraction and then linking them together to form an implementation. Some of these models will exist independent of software platforms, while others will be specific to particular platforms.

MDD imposes structure and common vocabularies so that artifacts are useful for their main purpose in their particular stage in the life cycle (such as describing an architecture), for the underlying need to link with related artifacts (earlier or later in the life cycle), and to serve as a communication medium between participants in the project [10].

It enables reuse at the domain level, increases quality as models are successively improved, reduces costs by using an automated process, and increases software solutions' longevity [9].

The underlying motivation for MDD is to improve productivity—that is, to increase the return a company derives from its software development effort. This benefit can be seen in two ways [12]:

- It improves developers' short-term productivity by increasing a primary software artifact's value in terms of how much functionality it delivers.
- It improves developers' long-term productivity by reducing the rate at which a primary software artifact becomes obsolete.

The primary goal of MDD is to raise the level of abstraction at which developers operate and, in doing so, reduce both the amount of developer effort and the complexity of the software artifacts that the developers use [10].

Thus with MDD *there is a separation of the model from the code, the user works on a platform independent model, selects the specific target platform, and the tool generates the code. Productivity is raised because the auto-generation takes care of all the plumbing code [13].* There is also a single language to use in building the model, the auto-generation will take care of SQL database calls, Java or .NET platform specific code, XML, and JavaScript for Web clients. This makes it easier to rapidly build applications and avoid the code testing cycle, as code is 100% generated. Naturally, testing still needs to be performed to test the design against the project requirements.

The major advantage of this is that we express models using concepts that are much less bound to the underlying implementation technology and are much closer to the problem domain relative to most popular programming languages. This makes easier to specify the models, understand them, and maintain them; in some cases, it might even be possible for domain experts rather than computing technology specialists to produce systems. It also makes models less sensitive to the chosen computing technology and to evolutionary changes to that technology [14].

This has enabled the creation of far more complex applications without increasing the project management work load, or conversely, building like-for-like applications faster, cheaper, and with higher quality, compared with lower-level techniques [13].

Model-driven approaches increase developer productivity, decrease the cost (in time and money) of software construction, improve software reusability, and make software more maintainable. Likewise, model-driven techniques promise to aid in the early detection of defects such as design flaws, omissions, and misunderstandings between clients and developers [1].

Model-Driven Architecture

The Model Driven Architecture is a framework for software development, defined by the OMG. Key to MDA is the importance of models in the software development process [15]. Within MDA the software development process is driven by the activity of modelling the software system.

OMG has created a MDA model to create a base for MDD, so it can be seen as a subset of MDD, as it is the OMG particular vision of MDD [16].

The MDA development life cycle is not very different from the traditional life cycle. The artifacts of the MDA are formal models, i.e., models that can be understood by computers. The following three models are at the core of the MDA [17]:

- **Platform Independent Model (PIM)**, a model with a high level of abstraction, which is independent of any implementation technology.
- **Platform Specific Model (PSM)**, a model tailored to specify your system in terms of the implementation constructs that are available in one specific implementation technology. A PIM is transformed into one or more PSMs.
- **Code**, a description (specification) of the system in source code. Each PSM is transformed into code.

In MDA, PIMs are initially expressed in a platform-independent modelling language, such as UML. The platform-independent model is subsequently translated to a PSM by mapping the PIM to some implementation language or platform (e.g., Java) using formal rules [18].

The higher abstraction level is supposed to make MDA easier to use and easier to understand. It also provides to certain degree of platform independence. Some of the other key benefits [19] from using MDA are:

- **Portability**, increasing application re-use and reducing the cost and complexity of application development and management, now and into the future.
- **Cross-platform Interoperability**, using rigorous methods to guarantee that standards based on multiple implementation technologies all implement identical business functions.
- **Platform Independence**, greatly reducing the time, cost and complexity associated with re-targeting applications for different platforms-including those yet to be introduced.
- **Productivity**, by allowing developers, designers and system administrators to use languages and concepts they are comfortable with, while allowing seamless communication and integration across the teams.

This brings to a reduced cost throughout the application life-cycle, reduced development time for new applications, improved application quality, increased return on technology investments and rapid inclusion of emerging technology benefits into their existing systems.

Model Transformations

MDD aims to develop, maintain and evolve software by performing model transformations [20].

So, model transformations are touted to play a key role in MDD. Their intended applications include [21]:

- Generating lower-level models, and eventually code, from higher-level models;
- Mapping and synchronizing among models at the same level or different levels of abstraction;
- Creating query-based views of a system;
- Model evolution tasks such as model refactoring;
- Reverse engineering of higher-level models from lower-level models or code.

Working with multiple, interrelated models requires significant effort to ensure their overall consistency. In addition to vertical and horizontal model synchronization, we can significantly reduce the burden of other activities, such as reverse engineering, view generation, application of patterns, or refactoring, through automation. Many of these activities are performed as automated processes that take one or more source models as input and produce one or more target models as output, while following a set of transformation rules [22]. In other words, model transformations allow us to get PSMs from PIMs, as shown in the next figure:

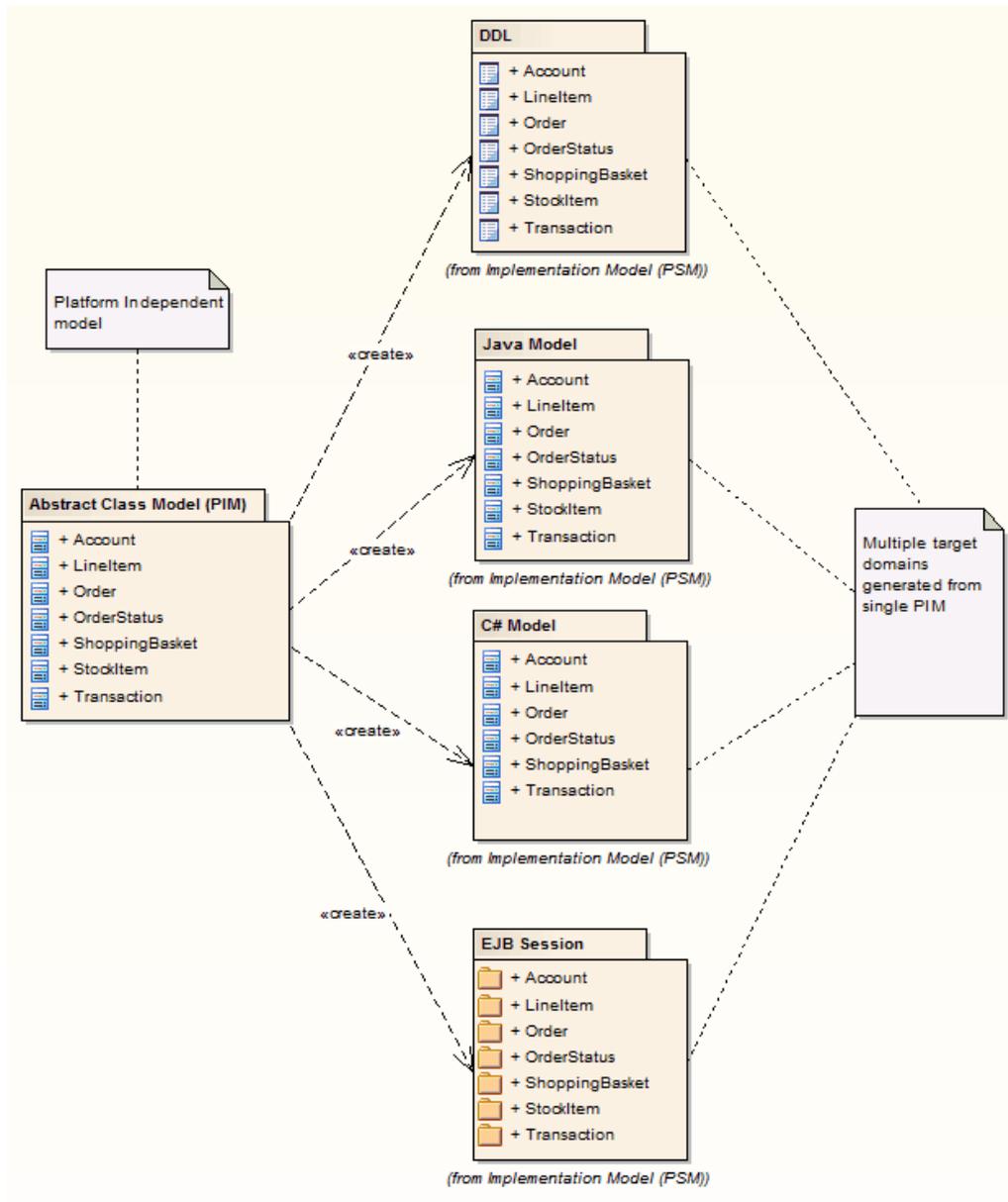


Fig. 3. - Example of model transformations (from <http://www.sparxsystems.com>)

Figure 3 shows some examples of model transformations, where the original model is represented through a PIM and multiple PSM are created from transformations.

Rapid development tools make use of this concept, making the transformations automatically from the PIM to one (or more) PSM.

3.2. Rapid Development Tools

There are many tools that let us to make use of the concepts that we already mentioned, like MDD and MDA. These tools allow us to build software through the automatic generation of the code from models. We'll call these tools rapid development tools since they allow the rapid development of applications.

We have chosen Artech's Genexus, Quidgest's Genio and the Outsystems Platform to analyze because of the similarities and differences that unite these tools.

In the next sections we present the tools and we'll make a critical analysis of the types of visualization that they allow.

3.2.1. Genexus

Genexus¹ is an intelligent tool developed by Artech aimed at assisting analysts and users throughout the lifecycle of applications.

The design and prototype are done and tested on a Windows environment. Once the prototype is fully approved by users, the database and the application programs for the production environment are generated and/or maintained in a fully automatic way.

Genexus supports business processes through a WorkFlow supplementary tool (GXFlow), as well as Reporting (GXquery), Business Intelligence (GXplorer) and portal Building (GXportal). It also allows developing mobile applications.

It has an option to deploy to the cloud which facilitates cloud prototyping and it allows us to use the MDD concept as it is a program to make other programs. With Genexus it's possible to describe the high-level requirements and the tool generates the data model and the native applications, giving full technology independence.

As a concept, MDD implicitly puts the user at the *heart* of everything that happens in the definition and description of a Business system.

To develop the "Model" requires domain expertise that is naturally known and possessed by the user or business owner. Genexus takes this information and generates the software and data structures that are required to bring the Business Model to life [23].

With Genexus, the developer starts from collecting Users Data Views as the base model to derive a deterministic Entity-Relational data-model to drive the business information architecture.

¹ www.genexususa.com/

Genexus also have some views that allow the user to see the objects of an application, as shown in figure 4:

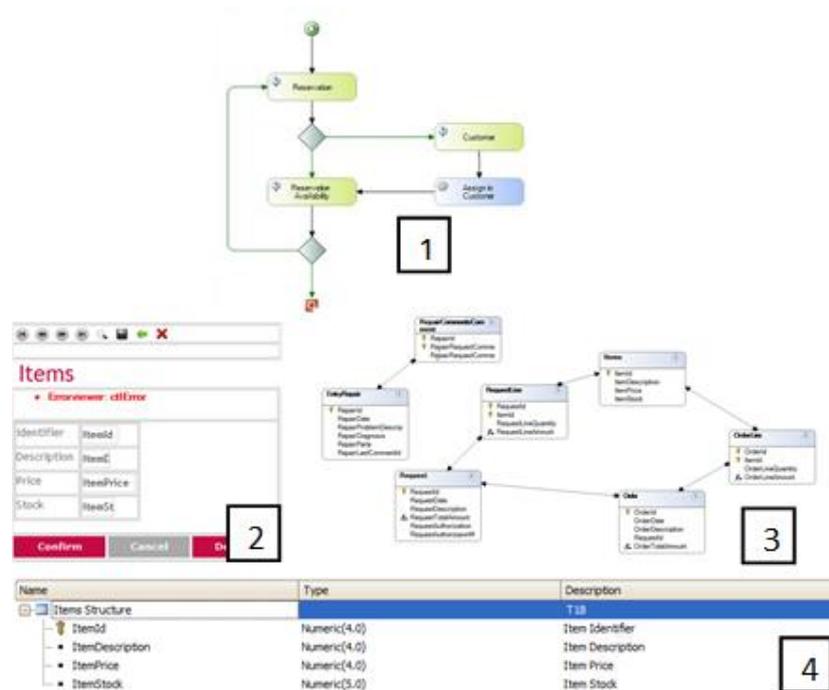


Fig. 4. - Examples of Genexus Views (1 - Business Process 2 - Form, 3 - Relationships between tables, 4 - Table)

The problem we see with these visualizations are the lack of navigation and interactivity between them. For example, for a user be able to see the relationships between the tables in an application (3) he has to create a diagram and then drag and drop the tables from the list of tables to the diagram. It is difficult to navigate through these views without losing the context or the focus. And there is no view that allow the user to have a general overview of the application with all the objects.

3.2.2. Genio

Genio² is an integrated development platform, created by Quidgest, to manage dynamic metamodels of functional specifications and automatic code generation.

It is a platform for rapid development of comprehensive information systems, combining model-based development with automatic code generation in different programming languages such as MVC, PhoneGap, Web services, HTML 5 or C#.

² www.quidgest.pt/q_genioPT.asp

Genio allows the programmer to design graphical user interfaces interactively while the compiler invisibly generates the corresponding source code. Also, Genio generates and manipulates code to automate code refactoring that would require multiple (error prone) manual steps, thereby improving developer productivity [24]. Genio is responsible for the entire development process, without any further needs for changes after generation. Any complementary code that has to be manually written is isolated, protected and taken into account in each regeneration.

Its current architecture offerings are Back office (Windows, C++, MFC) and Web (C#, AJAX, web services), Silverlight, PLSQL and WCF WebServices. It also has some prototypes for Mobile, MS-Office task panes, Share point and Enterprise Java Beans.

Genio enables MDD for it operates as an IDE, creating a central interface to access the definitions, specialized tools and calls to the generator to create the final code of the solutions.

The generation is performed according to the model definitions (tables and fields of the database, validation rules, forms, menus systems, application resources, access levels and customer management). For the generation to be made, generators and templates are also needed. The templates are documents with instructions on what type of content should go to each portion of the code. The generator has two inputs, the definitions and the templates, and one output, the source code.

Thus, there is a separation of the model from the code, because the user works on a platform independent model, selects the specific target platform, and the tool generates the code. Just like MDD.

Genio doesn't possess a visual way (per say) to analyse the data and navigate through it. The most similar to representations of the models created by Genio is a view that can show the relationships between some objects of an application, as shown in figure 5:

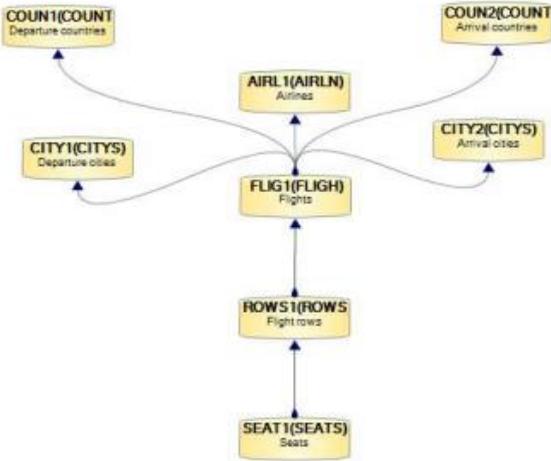


Fig. 5. - Relationships between objects in Genio

This visualization, by itself, does not give the user much information about the application and it should be combined with other views in order to be more useful.

3.2.3. Outsystems Platform

The OutSystems Platform³ is a high-productivity solution for the agile development and management of custom enterprise web and mobile applications. It allows development at the business logic level, with the platform generating the conventional code needed for deployment on the available technology. It focuses on accommodating rapidly changing business needs; scalability without arbitrary limits and with consistent ease-of-use, regardless of scale and complexity;

It is an agile platform, which allows developers to create web applications using a Scrum-based methodology, if desired. It can create both .NET and Java applications, using its database modelling tools, in conjunction with a visual modelling language operating at a business logic level higher than either Java or .NET [25].

The OutSystems Platform includes Business Process Technology which enables the design, execution and management of processes which are fully integrated with the applications built with the OutSystems Platform.

In the Outsystems platform, the models are data centric. Once the database model is defined, it is possible to quickly create the UI models and the business logic. On top of these it's possible to add business processes to execute long running transactions, timers, events, and human workflows. All models are integrated and type checked in real-time.

Like Genexus, the Outsystems Platform also has some views that can help the user understand the application, as shown in figure 6:

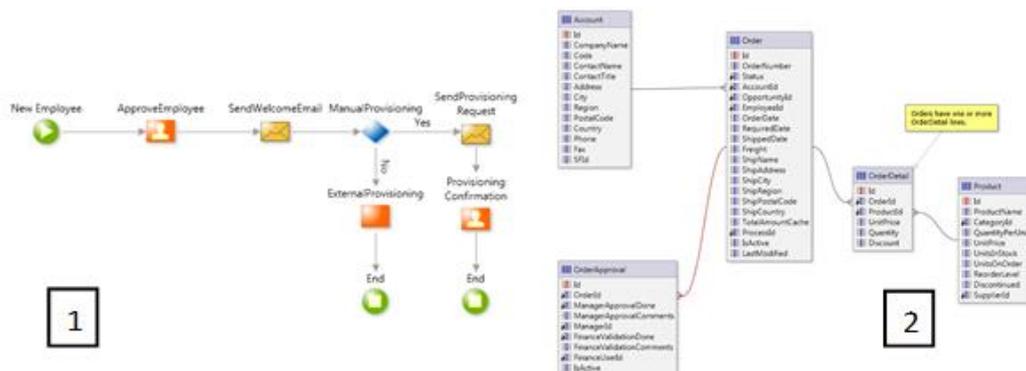


Fig. 6. - Examples of Outsystems views (1 - Business Processes, 2 - Tables and their relationships)

Once more, this visualizations are difficult to navigate and interact and they don't give a general overview of an application.

³ www.outsystems.com/platform/

3.2.4. Overview of the tools

As already noted, these tools have in common the use of the MDD concept. They allow the developer to define PIMs, mostly UML-like, and the tool generator makes the necessary transformations to create the PSM according to the chosen target platform. These tools raise the level of abstraction of the development of applications by separating the models from the code, which is generated automatically, like the database definitions of the application, i.e. the data model of the application.

Some of these tools already have a way to visualize the objects of the data model, mostly by ER diagrams and UML, but it makes use of the proprietary tools and their representation sometimes can be difficult to analyse. They also can have a way to visualize the business processes through BPMN, but it isn't possible to navigate through the different views of the models without changing the context or the focus.

3.3. Software Visualization

Software visualization [26] refers to the visualization of information of and related to software systems and their development process by means of static, interactive or animated visual representations of their structure, execution, behavior and evolution.

In other words, software visualization uses visual representations to make software more visible. Visualizations concerns the graphical (or semi-graphical) representation of information in order to assist human comprehension of and reasoning about that information [27].

A number of taxonomies have been proposed [27]. Two of the most interesting are those by Price, Baecker and Small (1998) and Maletic, Marcus and Collard (2002). The now classic taxonomy by Price, Baecker and Small (1998) identified six major categories of attributes: scope (the range of programs the system can take as input), content (the subset of information about the software that is visualized by the system), form (the characteristics of the output of the visualization), method (how the visualization is specified), interaction (how the user interacts with and controls the visualization), and effectiveness (how well the system communicates information to the user).

3.3.1. Software Visualization Tools

Most visualization tools that we found are more concerned in showing the data that is in an application, instead of showing the relationships between the models that describe the definitions of the application: the data model. Other examples are tools with the focus on the application code.

We found some visualization tools that allow the user to see the relationships between the tables in a relational database and that allow to identify some dependencies, but these visualizations don't seem

to allow navigation between them nor they show implicit relationships between elements. It's like they're made to a user that already knows what he wants to see, instead of discovering through navigation.

Some of these tools are Tioga and Tioga-2 [28], Polaris [29] and Shrimp views [30].

Polaris is a system for query, analysis and visualization of multidimensional databases and its user interface is depicted in Fig. 7:

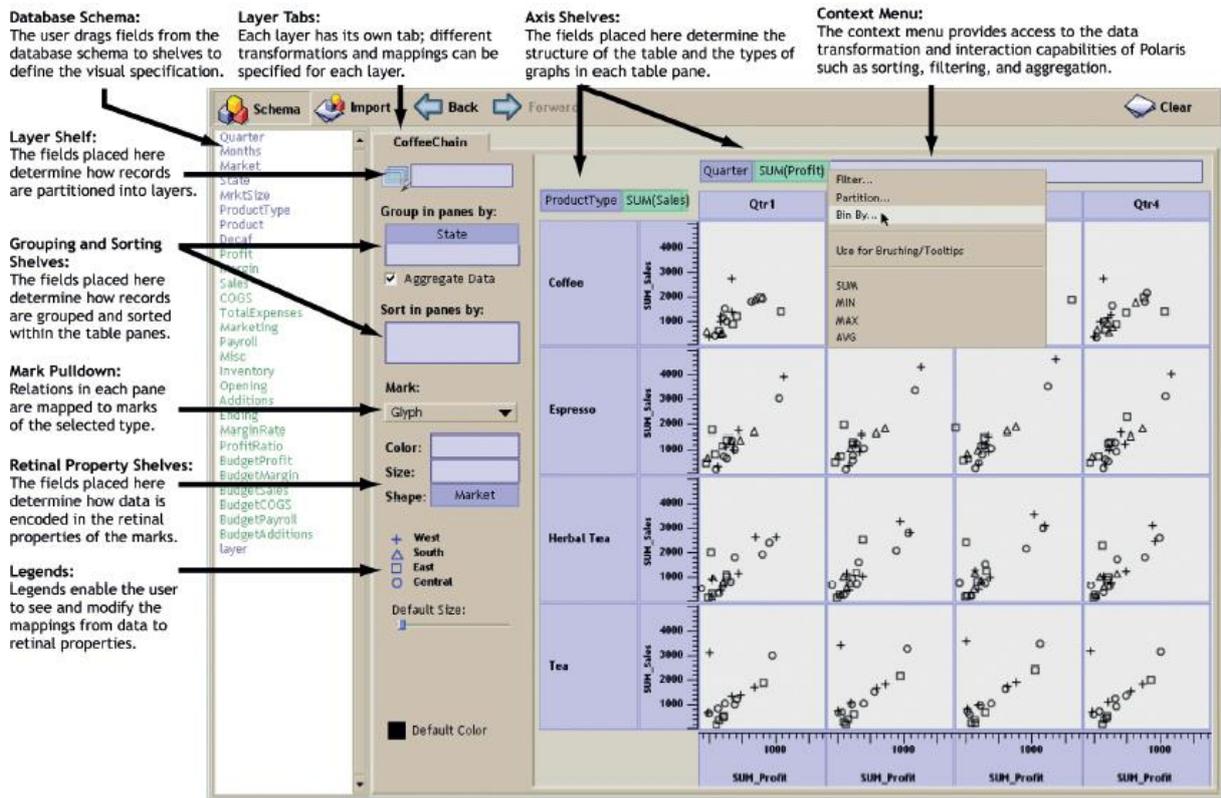


Fig. 7 – The Polaris user interface (from [29])

This tool has its focus on showing the data inside database tables and not in the model of an application, so it is not the kind of visualization that we want.

On other hand, Tioga and Tioga-2 are DBMS-centric visualization tools and they can show relationships inside a database, but they are designed to be used by programmers as they has a low abstraction level:

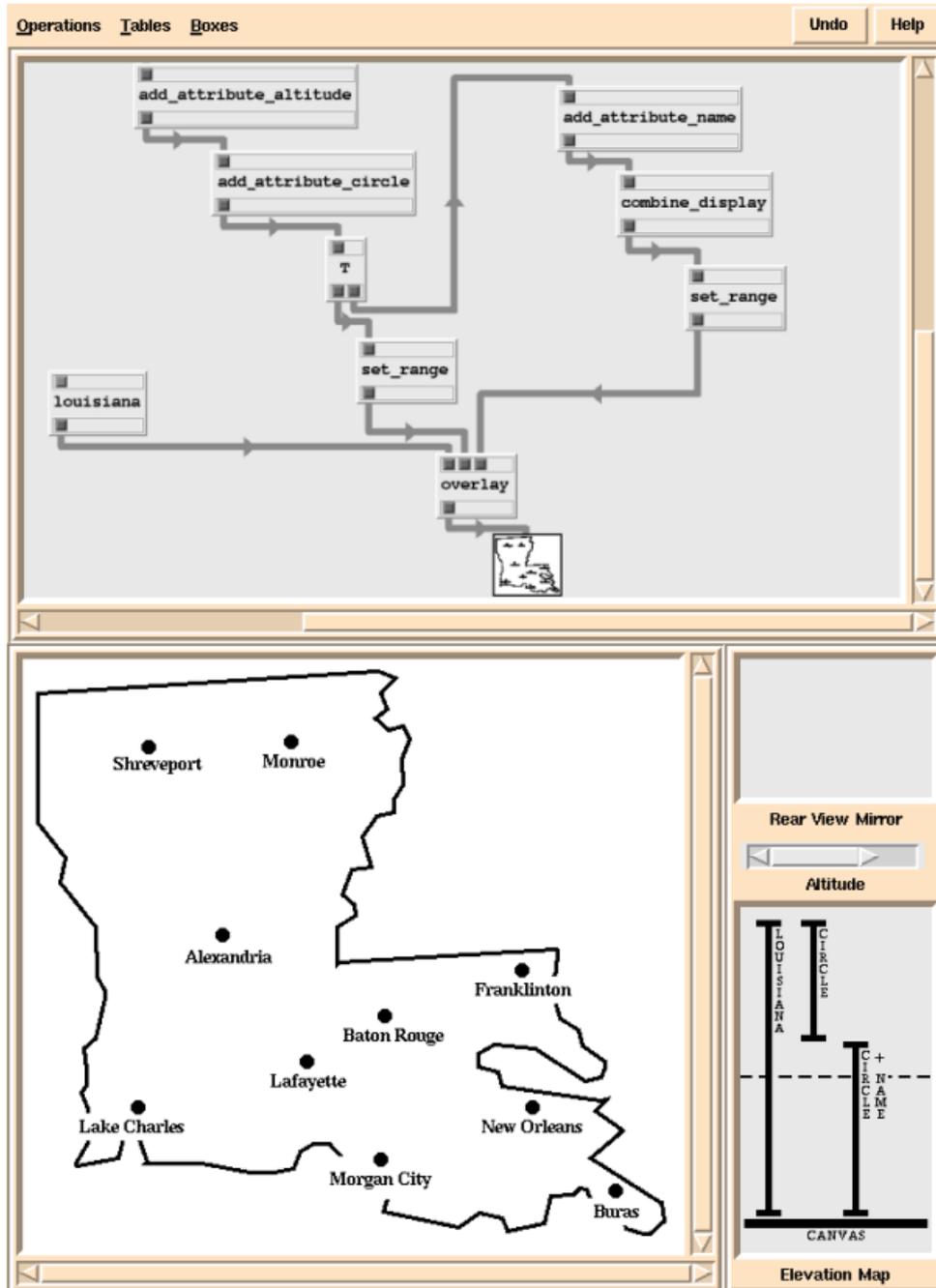


Fig. 8 – Tioga-2 user interface (from [28])

As shown in Fig. 8, Tioga-2 (a more powerful Tioga) lets the user see relationships in a database, but it is more easily used by programmers, since the authors describe a programmer model and state that it is based on the idea that an expert programmer constructs *POSTGRES* user-defined functions (boxes) and that a second programmer uses an editor to “wire up” visualizations [28].

The third software visualization tool that we analyzed was Shrimp Views, and it consists in [31] visualizations that combine the node-link diagrams with the fisheye filtering technique. The problem with this tool is that it is focused in the code, i.e., software structures:

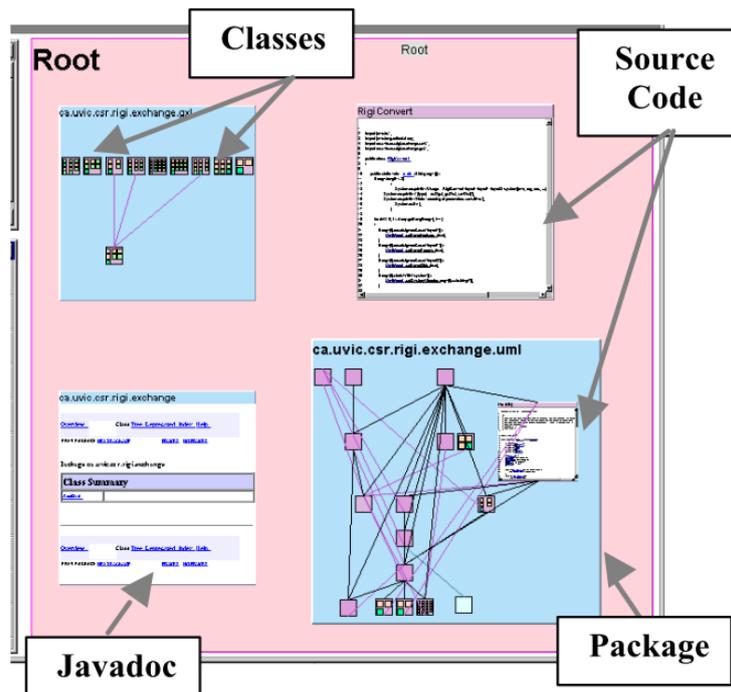


Fig. 9 – A shrimp view of a java program (from [30])

As shown in Fig.9 and mentioned above, this tools has its focus on the code developed and it requires programming skills (or, at least, programming knowledge) to understand.

3.4. Visualization techniques

There were some attempts at constituting taxonomies to differentiate the kind of visualization. We have chosen the taxonomy constructed by Shneiderman [32].

In this taxonomy are defined seven data types:

- **1D** - Linear data arranged in a sequential manner, e.g., alphabetical list of names, source code;
- **2D** - Planar or map data, e.g., photographs, maps, newspapers layouts;
- **3D** - Data with volume and with relationships with each other, e.g., molecules, buildings;
- **Temporal** - Data with start time, finish time with or without time overlaps, e.g., medical records, video editing;
- **Multi-dimensional** - Data that has multiples attributes that translate into points in an n-dimensional space, e.g., records in relational and statistical databases;
- **Tree/Hierarchical** - Items that are linked though hierarchy in a tree structure, e.g., computer directories, business organizations;
- **Network** - Items linked through a graph structure, e.g., World Wide Web.

From these types, we'll chose the most adequate to the kind of data that we want to visualize.

4. Objectives

This chapter corresponds to the Objectives Definition step of Design Science Research Methodology (DSRM).

We identified some criteria for good visualizations [33] and matched them with the type of information that we wanted to visualize. What we want to visualize are **different levels of abstraction** of the components of an application developed with a rapid development tool, i.e., its **objects**. These objects can be **menus, tables and forms** and the solution must use graphical representations, i.e., visualization techniques applied in this context to show the relationships between those objects by various levels of abstraction. We have chosen those object types because, after the analysis we made to rapid development tools, we concluded that those were the most important objects created with this kind of tool. Tables and forms are present in all the tools we analysed and the menus usually are composed by the other objects present in the application.

We also want to be able to see the **most relevant objects** of the application with few or without any interaction. The most relevant objects will be the ones with more dependencies, i.e., the ones that have relationships with more objects.

The proposed solution must show graphically, in 2D, the model of an application in a **stratified and navigable** way in order to find patterns, simplify the knowledge of the application and to show **clusters** of entities and its relationships to find the application core.

It is also important that we can visualize the **evolution of the application over time** in order to check and monitor the changes of the model and to identify the objects with more changes.

So, the criteria that we have identified for our solution are:

- **Ease of use** – the visualizer must be user friendly in order to make the users to want to use it;
- **Portability** – we want a visualizer that can be used with different rapid development tools;
- **Quantity of information that can be easily viewed** – we want to be able to show a great amount of data, so we will need to create filters according to the quantity of data to show in each moment;
- **Simplicity** – The information must be seen in a simple way in order to be easily understood. Also, tasks performed with the proposed solution must be done in the least amount of time and with the least effort possible;
- **Navigation and interaction** – The visualizer must provide a way to navigate through different levels of abstraction;
- **Context keeping** – In some situation it can be useful for the users to keep the context between visualizations;
- **Filters** – The visualizer must allow the user to filter the data according to their needs.

These criteria were defined through informal interviews with analysts and developers from Quidgest, which work with a rapid development tool, Genio. We also received some sight from specialists in the area.

5. Research Proposal

This chapter maps to the design and development step of Design Science Research Methodology (DSRM) and its output is an artefact, in this case an instantiation, that aims to solve the identified problem and the objectives defined earlier in this document.

As we identified in the problem section, software artifacts in industrial applications can consist of thousands of code files, making difficult to manage and analyse the system's complexity.

The first problem addressed is the management and analysis of the systems complexity. It is intended to extract from complex models the most relevant objects of the system without any additional information or interaction.

The second problem is concerned with the visualization of the models and the navigation between models inside and out of the same abstraction layer. Bi-dimensional interfaces that allow to visualize and manipulate data can also be used to improve the perception of the models.

In order to try to solve these problems, we propose the development of a model's visualizer that will allow to:

- Facilitate the complex model's visualization through 2D visualization techniques;
- Extract from complex models the most relevant objects of the system without any additional information or interaction;
- Visualize the models and the navigation between models inside and out of the same abstraction layer;

We have chosen 2D visualization techniques because, after a state-of-the-art analysis of the 3D models' visualization techniques, we realized that its application in this context wouldn't make much sense, since in the majority of the cases the models' legibility is drastically reduced in comparison to 2D visualization techniques. One of the major factors is that, in 3D, when projected in a screen (2D surface), hides a great amount of the model, needing rotation and translation interactions that can be too complex for a common user.

We proposed the following architecture for the visualizer:

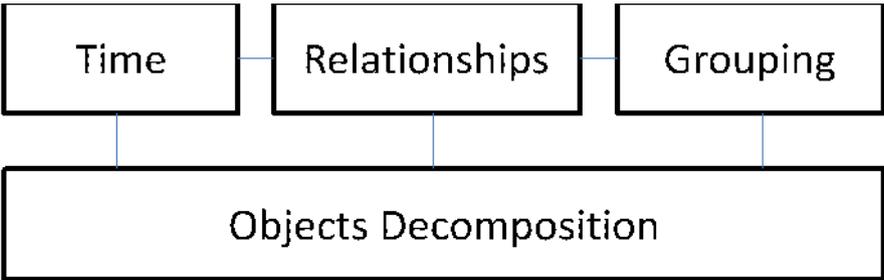


Fig. 10 – Architecture of the proposal

The visualizer decomposes the application in its more important objects. These objects will be present in the **Objects Decomposition** component in a way that the user can identify the most important ones without any or little additional interaction. For example, if a table has many connections with other objects, then, if there is an error with that table, all the related ones will be spreading that error.

Its **Time** component will allow users to see the changes to the objects through time, giving them an insight of how the application evolved since it began being developed. The user will know which objects were created, updated and deleted from the application and when these operations occurred.

The **Relationships** component will help visualizing the dependencies of objects in the data model of an application, giving the possibility of navigating through it discovering other connections.

The **Grouping** component will help to identify groups of models that relate in some context, i.e., how they are grouped relatively to some other components.

This architecture makes use of different visualization algorithms, each one with the characteristics needed regarding the kind of information that we want to see.

This stratified architecture also allows users to navigate freely through the abstraction levels and through focus.

We based our work on existing visualization techniques to represent the elements that we identified previously. These visualization techniques were chosen from the ones depicted in the taxonomy constructed by Shneiderman [31] and adapted to fit the information we want to visualize in order to meet the criteria previously defined.

Through this section we'll present visualization techniques to be tested. We divided these techniques into hierarchical, networks and multidimensional because they seem to be the types of visualization that better fit our purpose – visualize relationships and hierarchies among the many elements that compose an application with multiple attributes. These visualization techniques were chosen from the ones depicted in the taxonomy constructed by Shneiderman [31], that we explained in section 3.4.

The hierarchical visualization techniques [31] show items that are linked through hierarchy in a tree structure, as shown in figure 8. These visualizations can allow the user to identify the number of levels in a tree or how many children an element may have, for example.

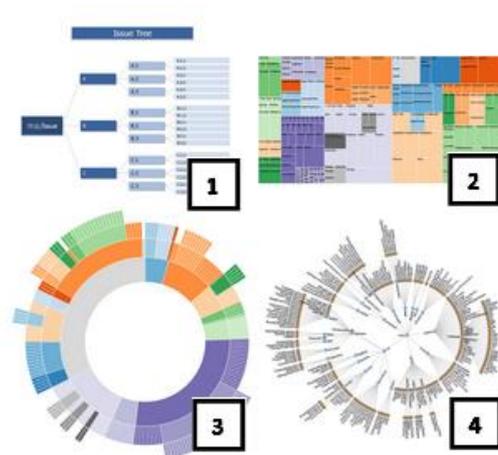


Fig. 11 - Examples of hierarchical visualizations (1 - General tree visualization, 2 - Treemap, 3 - Sunburst, 4 - Radial Tree)

The network visualization techniques [31] show items linked through a graph structure, as it can be seen in figure 9:

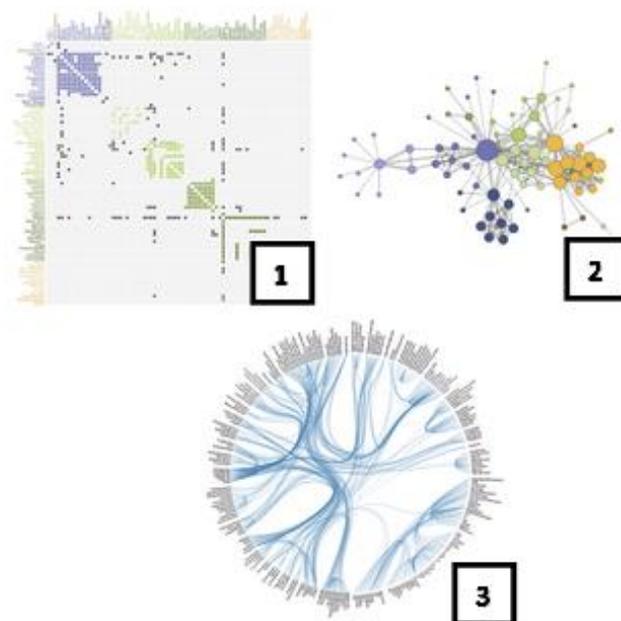


Fig. 12 - Examples of network visualizations (1 - Matrix, 2 - Node-Link diagram, 3 - Dependency Graph)

These visualization techniques can help the user to identify the relationships between elements and how they work together. Moreover, they can possibly show applicational modules to be reused.

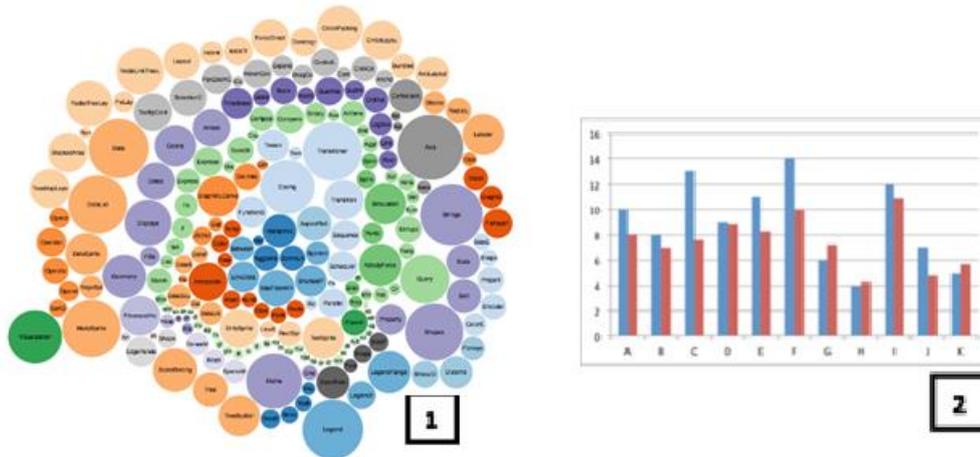


Fig. 13 - Examples of multidimensional visualizations (1 - bubble chart, 2 - bar chart)

Multidimensional visualizations, as the ones shown in figure 10, can be useful to see data with multiple attributes in a multidimensional space. For example, we could use a bubble chart to represent all the elements of an application's data model with the bubbles sizes arranged according to the element's importance, using different colours to represents different types; or the bar chart to represent the time component, where we can see the number of changes made to the objects through time.

We also considered ER diagrams to represent the relationships between objects, but usually these diagrams go at a lower abstraction level than we intended, sometimes showing all the objects attributes. Also, usually they are not interactive.

After choosing which visualization techniques to use, we had to choose the technology to implement them. We used the D3.js [34], a JavaScript library, made by Mike Bostock, which allows us to transform data documents. Besides JavaScript, it takes advantage of tools like HTML, SVG and CSS.

In this field, D3.js is one of the most used free libraries at the moment, in part, due to its unlimited ability to create custom visualizations and the great support given by its documentation, examples, and development community.

In the next subsection we'll explain which visualization techniques were chosen specifically for each component of the visualizer, with the reasons that led us to choose these techniques. We have chosen those visualization techniques having in mind the information that we want to visualize and the possibility of connecting them for the user to be able to navigate between them.

5.1. Objects Decomposition

As already mentioned, the visualizer decomposes the application in its more important objects. This view has the objective of giving the user an immediate sight of the relative significance of each object in the model of the application. We tried different visualization techniques, being the **bubble chart** the one chosen. We chose this visualization technique because it's possible to use its different dimensions in order to represent different object's attributes. The significance of each object is represented by its number of relationships to other objects and this is shown in the bubble chart by the size of each bubble, being the object type represented by the colour of the bubbles.

Other reason that led us to this visualization technique was the fact that it can show all the objects at the same time, fitting them all in the screen, which helps the users getting a general overview of all the application's objects.

We also made some changes to the usual bubble chart, making interactive, in the way that by clicking in a bubble, all the non-related ones fade out. This can help the users to understand the dependencies between objects and it's a starting point to connect the other visualizer's components.

5.2. Relationships

We have studied several graphics based in Force Direct automatic layout and Dot algorithms. The number of relationships between objects is exponential and each algorithm behaves in a different way regarding this complexity.

We have chosen a **node-link diagram** based in a force direct layout to represent this component of the visualizer because it can show the relationships between objects and it has a more acceptable response time.

Filters were applied in order to minimize the quantity of nodes shown in each moment. These filter include the type o relationship and the type of object.

5.3. Time

Each object is subjected to many modifications by many users through time. These changes are saved in the model and visualized in this view.

In order to make it easier for the users to understand, we discarded more complex visualization techniques that tackle the time dimension. We have chosen to represent a histogram through a **bar chart**, which takes advantage of different colors to represent different types of operations (updates, deletes, creates). It also takes advantage of a filter that allows to select the kind of timeline that the user want to see (day, month, and year).

This component keeps the context from the bubble chart, allowing the user to identify which objects suffered operations in each date and when a given object suffered the operations.

5.4. Grouping

The objects that make up a complex system lead to the creation of clusters connected between themselves, typically when they address a part of the system (as a storage management inside an inventory management, for example). To visualize these blocks we used a **matrix** view where each connection between two objects raises their proximity and value.

This way, we can visualize modules of objects that have strong connections between themselves and that can, potentially, represent a subsystem.

We have chosen to represent the way tables relate between themselves inside the menu objects, since a menu represent a group of tables and forms that are invoked during some interaction with the application made by the users.

We also included filters, to give the users a choice in the way they want to group the tables – by name, by frequency or by cluster (menu).

6. Demonstration

In this chapter we demonstrate how the proposal that was described in the previous section can be used to solve one or several instances of the problem depicted in Section 3. Subsequently, this section conforms to the demonstration step of DSRM, step 4.

6.1. Quidgest and FirstSightModel

Our demonstration was made in Quidgest⁴, which is a consultancy and software engineering company, with headquarters in Lisbon, Portugal, implementing a disruptive strategy for the IT sector, based on the creation and improvement of automatic code generation processes. Genio, Quidgest's platform for automatic code generation, enables deployment in a wide range of platforms (as mentioned in previous sections) and seamlessly integrates with a range of existing technologies.

This demonstration is also included in a research project called FirstSightModel⁵ that is being developed between Quidgest and INOV⁶. This project foresees the development of a Framework with three components: the visualization, the automatic extraction of models, and generation models of low-level from the high level. Our demonstration is included in the visualization component of the Framework that is being developed.

6.2. Model Visualization Tool

As we mentioned in the previous chapter, these visualizations were built on D3.js. So that a demonstration was possible, we developed, with help from Quidgest, a query that is able to return a .json file that will be consumed by the visualizations. This file can have the objects in the data model of an application, their relationships and/or their grouping. The data on the .json file is raw and the data processing is done in the JavaScript.

We tested our developed tool with several real applications from Quidgest in order to realize if our proposed tool performed well with different applications. This was extremely important because there are some applications bigger than other and our tool must perform well disregarding the size of the application.

In this subsection, we present the tool developed in order to tackle the problem identified. We will present screenshots of the tool for a specific application (a real one, used by Quidgest), along with the explanation of each one. In Appendix A we have screenshots that show the evolution of the prototype.

⁴ www.quidgest.pt/

⁵ www.quidgest.pt/q_ProjetosQRENPT.asp?LT=PTG

⁶ www.inov.pt/

The home page of the visualizer, shown in Fig.14, has a representation of the most important objects in the definitions of the application with their types represented by different colours and their size related with the number of relationships. Orange identifies Tables, red identifies Forms and blue Menus.

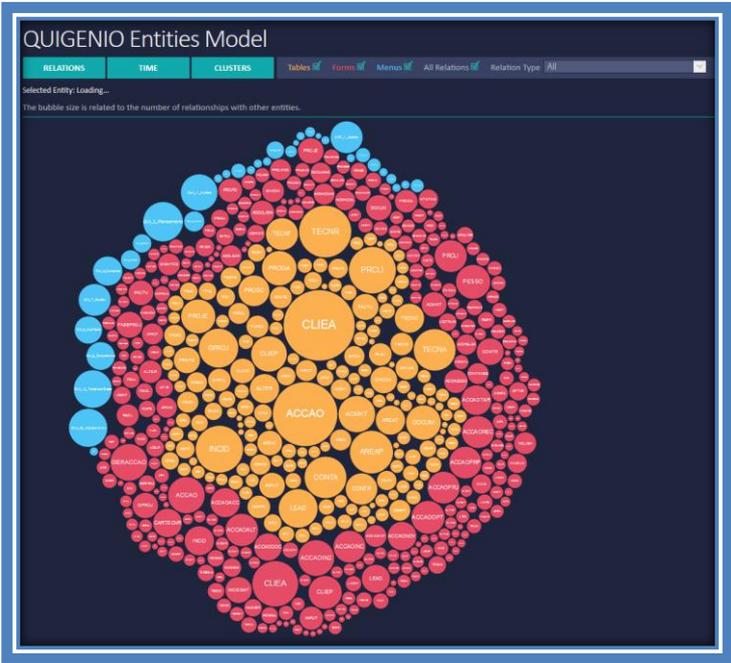


Fig. 14 – Visualizer’s home page

This maps to the objects decomposition’s component previously proposed for the visualizer.

The user can interact with the visualizer in order to gather more information about the definitions of the application. By clicking in an object, all the non-related objects fade out. This is represented in Fig. 15;

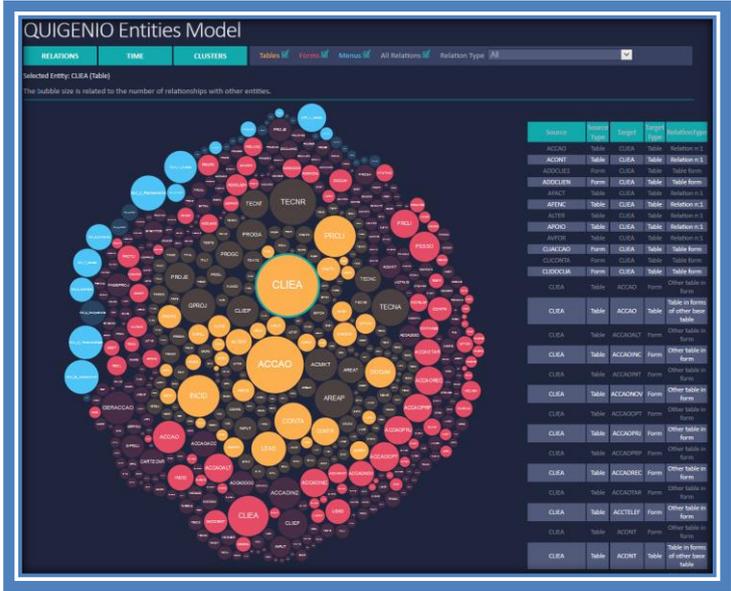


Fig. 15 - Relationships in bubble chart

For a better understanding by the users, all the highlighted relationships are kept in a table on the right of the chart.

It's also possible to filter these relationships by type, by choosing the relationship type in the upper right corner of the visualizer, or hide a type of object by deselecting its checkbox in the upper left corner. These features are represented in in Fig. 16:

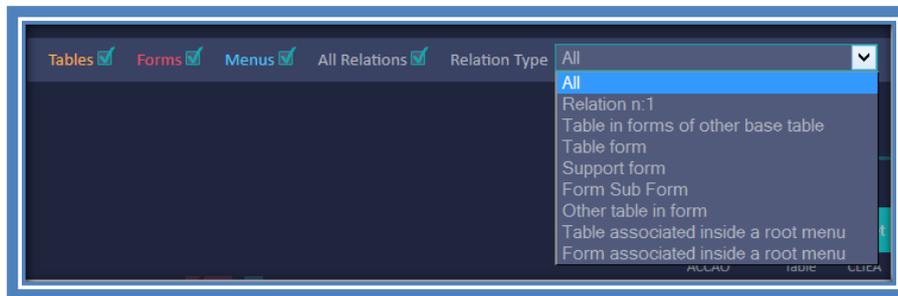


Fig. 16 - Bubble chart filters

This first view of the application in our visualizer is, perhaps, the most important one, as it gives the user a general overview of the application. It is especially useful as it allows to identify the most important objects of the application with nearly none interaction whatsoever. If an error is found in one object, the user can easily know how the error would propagate as he now knows which objects depend on that one.

By double-clicking in an object, the user can navigate to another view, centred in the selected object. This view is shown in Fig. 17 and maps to the relationship's component of the visualizer:

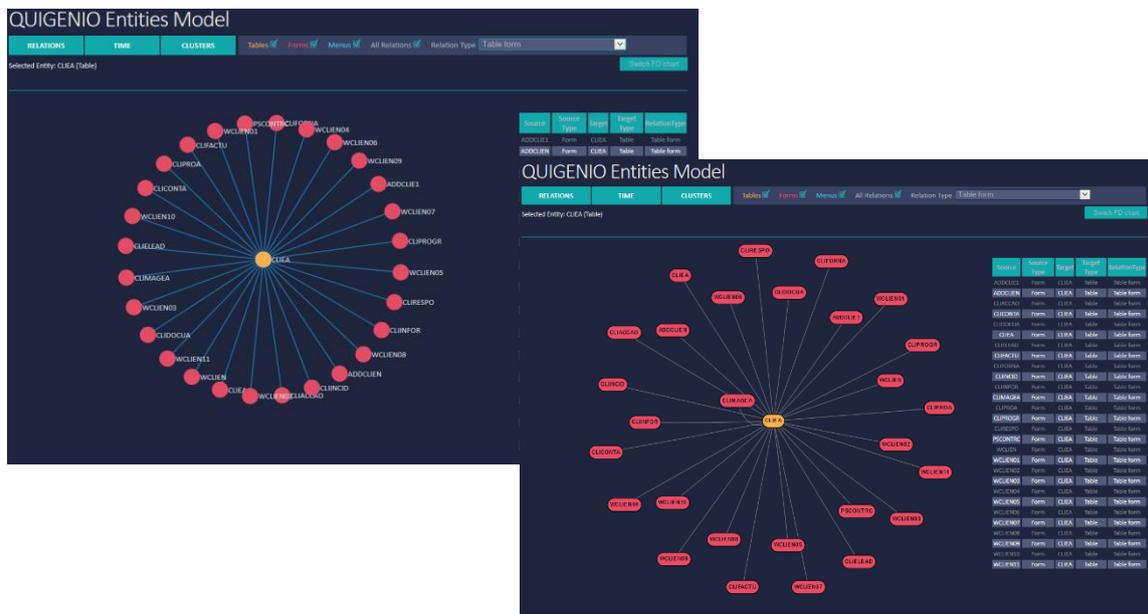


Fig. 17 – Visualizer's relationships page

As shown in the above figure, the user can change between two representations of this view. The one on the left is more appropriate when there are not many relationships, as it can get very fuzzy with. The

one on the right is an alternative that the tool gives the users when the other one gets more difficult to analyze. To change between them, the user only has to click on the button positioned below the relationship type drop down menu.

In this view, the user can navigate to other objects, being able to see their relationships to others, having the option of seeing the relationships between the objects of the same type as the one selected.

From the home page, it's also possible to navigate to a time view where the user can see the history of creation, update and delete of the objects. This is presented in Fig. 18, and it maps to the time component of the visualizer:



Fig. 18 - Visualizer's time view

By default, the time chart presents all the changes made to the definitions of the application, but the user can change it by clicking on an object from the bubble chart. By clicking on an object, the time chart changes to present just the information relative to that specific object. This is shown in Fig. 19:



Fig. 19 - Visualizer's time view for a specific entity (CLIEA)

Another feature of this view is the possibility of clicking in a bar from the time chart – this highlights the objects, in the bubble chart, that were created, updated or deleted in that date.

It's also possible to apply a filter to the time interval shown in the bar chart by selecting the area in the mini chart below the actual chart, as shown in Fig.20:

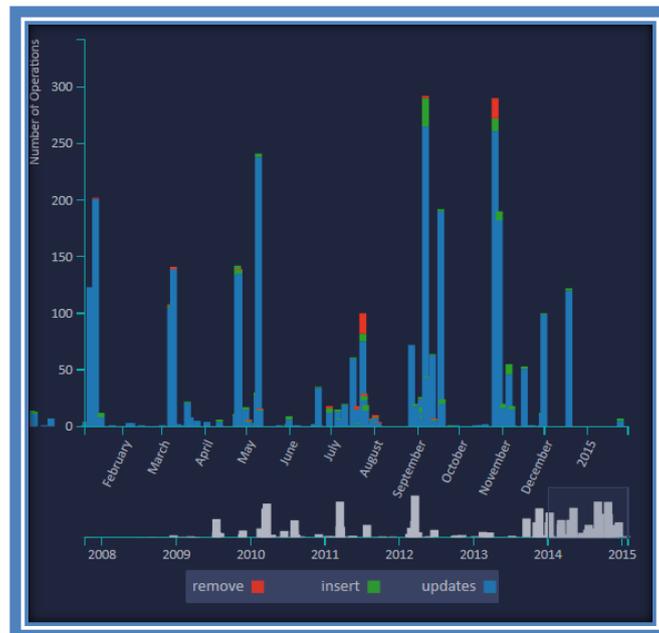


Fig. 20 - Timeline filtered

The above figure shows the timeline of the application filtered to only show operation that occurs in 2014.

We could have just shown the bar chart to give the user a notion of how the application was altered over time, but it made sense to keep the context from the visualizer's home page (bubble chart) because it's important to see the objects that "suffered" the operations. If the application (or a functionality of the application) stop working in a given moment, the user can check what objects were altered since the last time it worked perfectly – one of those must have been altered incorrectly.

Finally, it's possible to navigate to a clustering view of the tables of the application, as shown in Fig. 21:

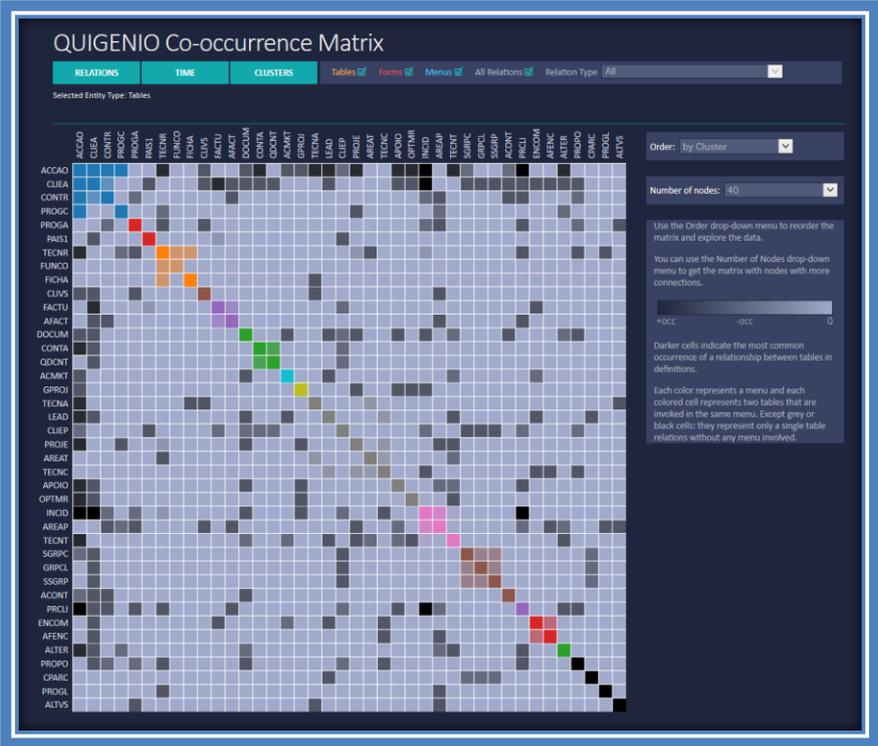


Fig. 21 - Visualizer's cluster view

This view maps to the grouping component of the visualizer and shows the tables grouped in a matrix diagram where each colour represents a menu where the tables are used. In this page, the user can select the number of tables that he wishes to see. It's also possible to rearrange the matrix axes by frequency (number of occurrences) and by name of the objects.

The above image shows the tables grouped by menu, and it's easy to see the "big spots" corresponding to different menus, allowing to identify what tables are most used in which menu.

This tool is already integrated in Quidgest's Genio, as shown in Fig. 22:

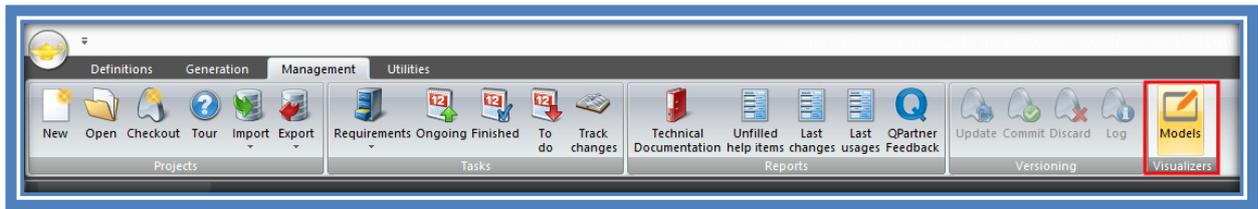


Fig. 22 - Model Visualizer in Genio

When the users have an application's definitions open, they can already use the visualizer to navigate through its data model by clicking on the model visualizer ribbon, as shown in the previous figure. The visualizer will then open with the data according to the definitions that the user has previously loaded. The data to be consumed by the tool is loaded at the start of the application with the purpose of speeding the user interaction with the tool in later moments.

7. Evaluation

In this chapter we describe how we intend to proceed with the evaluation of our proposal. This description corresponds to step 5 of DSRM, Evaluation. With this assessment we intend to establish that the proposal we offer supports the solution of the problem statement.

7.1. Usability Tests

In order to evaluate the feasibility of our proposal [35] and demonstration we performed tests of a quantitative nature, namely usability tests, with 10 users. These tests were made at the users' workplace, as it is the environment where they would be using the tool in normal circumstances. All the users performed the tests with the same data, i.e., using the visualizer with the same real application with real data, as we aimed to simulate tasks that they would perform with the proposed tool. The fact that all the users performed the tests with the same application allowed us to measure some usability metrics like: time taken to complete a task, number of errors and number of mouse clicks.

The methodology used to perform the tests, as well as the main results are presented in the next subsections.

7.1.1. Methodology

Since the users can interact with the developed tool in many ways, it was essential that we explained it first. We began by making a demonstration (the same for every user) with a duration of about 5 minutes. After this demonstration, each user was encouraged to try the visualizer and navigate freely through the application definitions, without knowing the tasks that he would be asked to perform.

The tasks order was randomly selected, since there is no dependency between them, but all users performed the tasks in the same order to ensure that everyone had the same experience during the tests and that the test's results were not influenced by potential experience gained during its execution. All tasks began in the visualizer's home page and every filter applied in previous tasks was removed.

During the execution of the tasks we measured 3 usability metrics: time taken to complete a task, number of errors and number of mouse clicks in each task. We used a program to save the pc screen during the tests in order to facilitate the analysis the metrics.

The tasks were created with the goal of evaluating the usability of each visualization technique used in the visualizer, i.e., testing each page or view. But the tasks also had the purpose of evaluating more specific aspects of the tool. The tasks, along with these aspects are presented in the next table:

Task 1	Identify the table with more relationships in the application. How many relationships does it have?
Objectives:	
<ul style="list-style-type: none"> • Evaluate if the users can identify the most important objects in the application with few or without any interaction; • See if the users understand that the mouse over function in the home page allows to see how many relationships each object has. 	
Task 2	Identify the table forms of the table with more relationships in the application. Of these forms, identify the one with more relationships and then find its support forms.
Objectives:	
<ul style="list-style-type: none"> • Evaluate if the users can properly use the filters in the home page or in the relationships page (the filters are the same in both pages); • See how the users navigate and interact with the tool in a more complex task. 	
Task 3	Identify the cluster (menu) that relates the tables with more relationships in the application.
Objectives:	
<ul style="list-style-type: none"> • Evaluate if the users understand the purpose of the cluster's page; • See if the users can properly use the filters in this page and if he understands what is represented. 	
Task 4	Find the creation date of the table with more relationships in the application. How many times was it updated since its creation? When it was last modified?
Objectives:	
<ul style="list-style-type: none"> • Evaluate if the users understand the purpose of the bar chart that represents the time component; • Evaluate how the context keeping helps the users in this page; • See if the users understand that by clicking in an object on the bubble chart, the bar charts adjust to show only the operations performed to that particular object. 	
Task 5	Verify which objects went under any operations (inserts, removes or updates) in 15/02/2013.
Objectives:	
<ul style="list-style-type: none"> • See if the users understand that by clicking in a bar from the bar chart the bubble charts adjust itself to show which objects suffered operations in that specific date: • See if the users can select a date by properly using the timeline filter; 	

Table 2 – Tasks and their objectives

After the tests, we asked the users to answer a quick survey, in order to register how they felt about the visualizer. In appendix B we present the survey used.

This survey had 10 standard questions based on the work of John Brooke – The System Usability Scale [36]. In the end of the survey there was an open answer question to the users make any suggestion/improvement that they would like to see implemented in the visualizer.

7.1.2. Users

We tested with a group of 10 users giving preference on the ones that would use the visualizer in the future – Quigest’s Genio developers. Since to date, there wasn’t much availability from Genio developers, we also tested with some other users that had some experience working with rapid development tools. The major part were involved in the FSM project.

Our testing group was composed by 9 men and 1 woman with ages varying from 20 to 40 years of age. During the tests, we noticed that some users didn’t take fully advantage of the demonstration made before the test and, although we asked them to think before doing any action and to tell us what they were thinking, some rushed in.

7.1.3. Usability tests results

After the tests conclusion, we summarized the metrics measured. The following table resumes the observed data and, for each task, we calculated the average, standard deviation, maximum and minimum values observed for each metric (clicks, errors and time taken):

Task	Mouse clicks				Errors				Time (seconds)			
	\bar{x}	σ	Max	Min	\bar{x}	σ	Max	Min	\bar{x}	σ	Max	Min
Task 1	0	0	0	0	0,1	0,3	1	0	1,3	0,64	3	1
Task 2	10,1	1,87	13	7	1,9	0,94	3	0	72,9	16,91	96	40
Task 3	5,2	1,17	7	4	0,9	0,83	2	0	36,7	6,97	50	25
Task 4	3,1	1,51	6	2	0,5	0,67	2	0	31,3	5,25	40	23
Task 5	6,6	1,91	10	3	0,4	0,49	1	0	30,7	8,26	45	17

Table 3 - Usability tests results

By analysis of Table 3, we verified that the users had more trouble performing the second task, since that one had higher values in all aspects measured. Task 2 was the more complex task that we asked our users to perform, since they had to go through more steps in order to finish it. Only one user was able to finish this task without any error. The most common error in this task was related with the use of the bubble chart filter for the first time, as the majority of the users tried to select the relationship type

filter before selecting the object of which relationships he wanted to see. This was a useful feedback, since we already changed the interface to allow the selection of the filter at any time.

Some users also felt some difficulties when performing task 3. Some didn't realize that this task was meant to be done through the visualizer's cluster view. The feedback given in this task was important, since we understood that "Clusters" wasn't a good name to identify this view.

On the other hand, task 1 was the most successful of all the tasks, as it was the simpler one. One of the major objectives of our proposal is to give the user the possibility to see the **most relevant objects** of the application with few or without any interaction. This results of task 1 show that all users were, almost instantly, able to find the most relevant table in the application. This can be widespread to all other objects in the application, since the principles are the same. The only error that occurred when testing this task was when a user rushed in to give an answer without properly looking to the chart presented in the tool. In the application used in the tests, the two more relevant tables have a similar number of relationships and, because of the user's rush, at first he didn't took the time to mouse over the two tables to see which one had, effectively, more relationships.

The tasks respecting the visualizer's time component (tasks 4 and 5) were performed with more confidence by the users, since they easily understood what they had to do. The aspect that the users made us notice was the fact that some of them had some difficulty using the time line filter: some made a lot of mouse clicks just to try to select the area of the chart that they wanted to see (most didn't understood that all they had to do was to select a portion of the chart and then drag the mouse to cover what they wanted). This is reflected in the average time and clicks of task 5 since the most time spent in this task was trying to select the portion of the chart that they wanted.

The following figure gives a more visual way of analysing the average metrics measured:

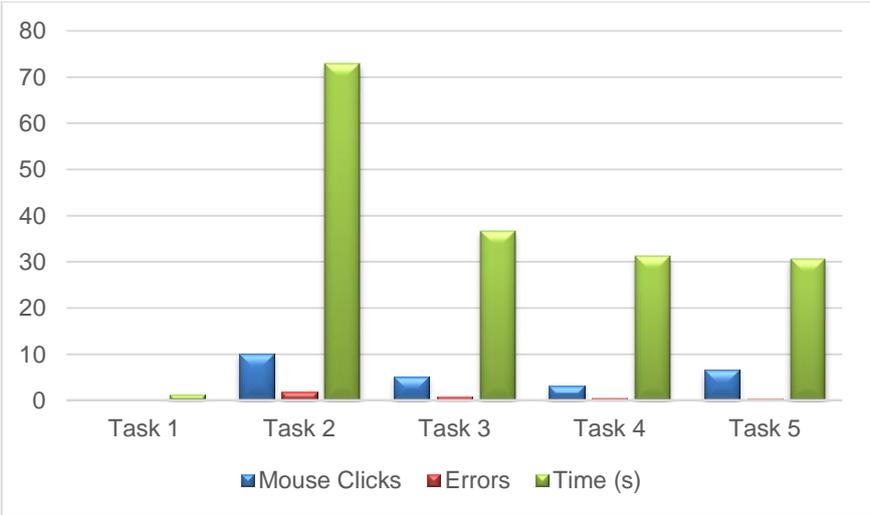


Fig. 23 – Average measured metrics

As it can be seen in Fig. 23, after task 1, the time spent to perform the tasks and the number of errors decrease in average, along the test. So, we believe that when the users star using the tool more often they will be using it more efficiently. Appendix C has the metrics measures for each task.

7.1.4. Survey results

The survey had a combination of 10 standard questions based on the work of John Brooke – The System Usability Scale [36]. This had the purpose of evaluating the usability of the visualizer, as well as giving us some insight of its utility. Table 4 shows the results of the SUS evaluation:

SUS Score	
\bar{x}	81.75
σ	7,67
Max	92.5
Min	65

Table 4 - System Usability Scale score

As seen in the previous table, the average score obtained was 81.75 which is a good indicator of the visualizer's usability. Even the users that had more difficulty performing some tasks, gave the impression that the difficulties were justifiable by being the first time they were seeing the visualizer. The standard deviation of the SUS score was 7.67, which isn't much, showing that there wasn't a great difference between the values.

The following figure shows the average result, per question:

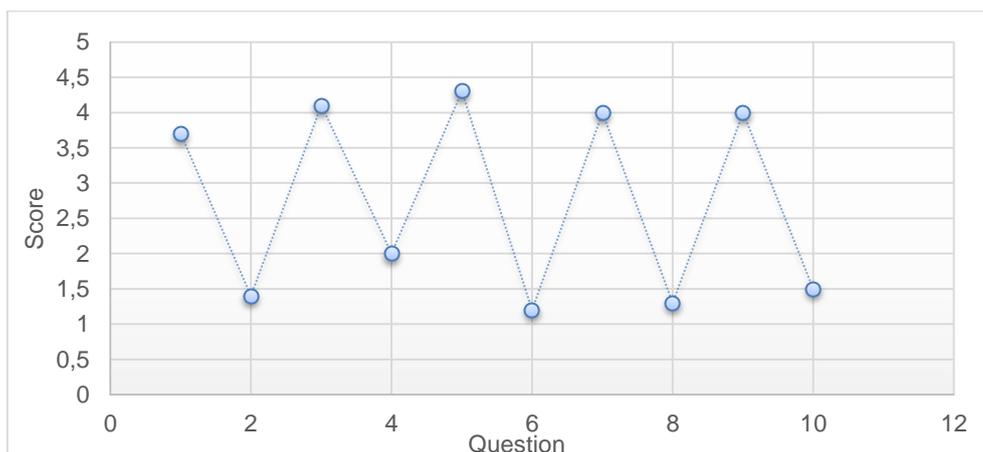


Fig. 24 - Survey's average results per question

Fig. 24 shows that the users thought that the visualizer had its functions well integrated and it doesn't have inconsistencies.

After these 10 questions, the survey had an optional open response question. Most users gave some suggestions, like:

- Changing the name of the clusters tab to a more perceptible name;
- Allowing the selection of filters before selecting an object;
- Making the table that supports the relationships' visualization interactive, being an alternative to the chart;
- Changing the nomenclature of the label in the time line chart to be more perceptible.

When all was finished, we had a talk with some users – mainly the users that will use this tool for real – and asked them a few questions about the utility of the developed visualizer. More specifically, we asked them if they thought that the tool was useful and what would be the function that they would use the most and why. The responses included:

- “The time function can be very useful, mainly when, for some reason, an application's functionality stops working and nobody knows why, since the last time the functionality was used it was working well. With this time view we can see when and what changes were made to the objects that compose that functionality”;
- “The cluster's view can be helpful when trying to see which tables work together in some context and allow to identify modules that can be reused”;
- “It can help identifying the dependencies between objects, helping to see how an error would propagate”;
- “The bubble chart was very interesting, it can give the users a quick sight over the application's objects and their importance”.

These tests were very important to the evaluation of our proposal and demonstration since we got information and feedback that wouldn't be easy to have without them.

7.2. Evaluation Overview

Through the tests, questionnaires and interviews made during our artifact evaluation we took some conclusions regarding the 5 system dimensions referred in [37]. These dimensions are: goal, environment, structure, activity and evolution. Each of these dimensions is characterized by some criteria. For each one, we present our conclusions:

- Goal
 - Our solution is **efficient**, since the developed artifact produces the desired effect: we met all the criteria defined in the objectives section of this document;
 - Our solution is **valid**, since it correctly achieves its goals;

- Environment
 - Our solution's environment is **consistent with people**, since it's useful (or can be useful), understandable and easy to use;
 - Our solution's environment is **consistent with an organization**, since we tested in Quidgest and it was approved by all that were involved in any way in its development process, including top managers;
- Structure
 - Our solution's structure is **simple**, since the information is seen in a simple way in order to be easily understood. Also, the tasks performed with the proposed solution, in the tests, were done in seconds, even the ones that users found more difficult;
- Activity:
 - Our solution is **complete**, since it has the functionalities desired by the users;
- Evolution
 - Our solution is **robust**, since new functionalities can easily be integrated with the current ones. It's also easy to add more types of objects and new filters according to the future necessities of the users and/or the organization

These dimensions have more criteria than we presented above, but some of the criteria wasn't applicable to our research.

8. Conclusion

This research follows the Design Science Research Methodology, since it can be applied in the context of Information Systems through the creation of IT artifacts that solve real-world organization problems.

Our research is expected to contribute to the implementation of several visualization technique prototypes that can be applied to the data model of an application that is developed through a tool that uses MDD concepts.

Those prototypes are navigable, interactive and compose a visualizer that allows the user to navigate through the application's data model, between different levels of abstraction and without losing the context and/or focus. We tested our artefact with 10 users and the results have shown that our prototype had a nice usability and can actually help

We expect that this visualizer will improve the way the dependencies between objects in a data model are seen and evaluated in order to identify the components that implement a given part of the application and that can be reused in other applications that share that same behaviour. We also expect the use of our artifact can help developers and analysts in analysing how the system really works and how they can improve it or detect errors.

8.1. Lessons learned

Our research raised several aspects worth mentioning. Some resulted from the Related Work and from the design phase of our research while others derive from the experience and feedback obtained during the demonstration and evaluation phases.

First and foremost, one of most important the lessons learned is connected to the awareness of a research methodology in this field of study. The use of the DSRM methodology provided us the tools on how to conduct a well-organized and successful research study.

Having proposed, coordinated and conducted a series of tests to different visualization techniques when applied to the generated objects in the model definitions of an application we have learned and gotten a new vision on the utility of the visualization techniques tested. And we were able to choose the ones that better fit with our purpose.

We learned that the visualization of data models can make possible to researchers, analysts and engineers to get an insight of this data model in an effective and efficient way. This was verified through our study of the work related to the problem, as well as through the tests and interviews we made.

8.2. Research Communication

In order to communicate the problem and its importance, the artifact, its utility and novelty, the rigor of its design, and its effectiveness to researchers and other relevant audiences such as practicing professionals, we wrote this thesis and we are preparing a presentation in the scope of the FSM project. Some minor presentation were already made during this research and the next one will be the final one where we'll present all our final results.

We are also finishing a research paper to submit to a conference. This paper will also help to disclose the work done during the FSM project, as well as the research we've done.

8.3. Limitations

As it normally occurs in a research study, there are some limitations to our work.

One of the criteria that we've defined in chapter 4 was portability. We wanted to create a tool which could be used with different rapid development tools. In order to use it with a different rapid development tool, it is necessary to develop a query to extract from the definitions database a .json file (with the exact structure we defined) to be consumed by the visualizer and create the charts. The construction of the query is not trivial, and it can possibly be different for every rapid development tool, since each tool can have a different way of constructing the data model.

Another limitation that we found is related to the usability tests. We were only able to test with 10 users due to lack of availability from other areas at Quidgest. We wanted to test with at least 20 users, but at the time that was not possible. Despite that, we intend to perform a second round of user tests at Quidgest until the end of the FSM project, and after we made the necessary corrections to the developed visualizer, as a result of the tests already performed.

8.4. Future Work

As future work, we think it would be interesting to demonstrate our proposal in other companies using other rapid development tools, but since this work was made in the scope of a research project with a real company we don't know if it is going to be possible.

It would also be interesting to add a new component to the developed visualization tool, a processes component, which would allow to have a new abstraction at a higher level and to see which objects were used in each business processes. This would help the company to align its applications with its business processes.

Finally, and as we explained with our work limitations, we didn't had the chance to perform the usability tests with more users. We'll perform more user tests until the end of the FSM project, with different users.

Bibliography

- [1] Liddle, Stephen W. "Model-Driven Software Development." *Handbook of Conceptual Modeling*. Springer Berlin Heidelberg, 2011. 17-54.
- [2] Van Wijk, Jarke J. "The value of visualization." *Visualization, 2005. VIS 05. IEEE*. IEEE, 2005.
- [3] K. Peffers, T. Tuunanen, M. A. Rothenberger, and S. Chatterjee, "A Design Science Research Methodology for Information Systems Research," *J. Manag. Inf. Syst.*, vol. 24, no. 3, pp. 45–77, Dec. 2007.
- [4] Cabot, Jordi, Robert Clarisó, and Daniel Riera. "UMLtoCSP: a tool for the formal verification of UML/OCL models using constraint programming." *Proceedings of the twenty-second IEEE/ACM international conference on Automated software engineering*. ACM, 2007.
- [5] Walker, Robert J., et al. "Visualizing dynamic software system information through high-level models." *ACM SIGPLAN Notices*. Vol. 33. No. 10. ACM, 1998.
- [6] Teppola, Susanna, Päivi Parviainen, and Juha Takalo. "Challenges in deployment of model driven development." *Software Engineering Advances, 2009. ICSEA'09. Fourth International Conference on*. IEEE, 2009.
- [7] Kent, Stuart. "Model driven engineering." *Integrated formal methods*. Springer Berlin Heidelberg, 2002
- [8] Mohagheghi, Parastoo, and Jan Aagedal. "Evaluating quality in model-driven engineering." *Modeling in Software Engineering, 2007. MISE'07: ICSE Workshop 2007. International Workshop on*. IEEE, 2007
- [9] Mellor, Stephen J., Tony Clark, and Takao Futagami. "Model-driven development: guest editors' introduction." *IEEE software* 20.5 (2003): 14-18.
- [10] Hailpern, Brent, and Peri Tarr. "Model-driven development: The good, the bad, and the ugly." *IBM systems journal* 45.3 (2006): 451-461.
- [11] Mellor, Stephen J., ed. *MDA distilled: principles of model-driven architecture*. Addison-Wesley Professional, 2004.
- [12] Atkinson, Colin, and Thomas Kuhne. "Model-driven development: a metamodeling foundation." *Software, IEEE* 20.5 (2003): 36-41.
- [13] Azoff, Michael. "The benefits of model driven development." Butler Direct Limited (2008).
- [14] Selic, Bran. "The pragmatics of model-driven development." *IEEE software* 20.5 (2003): 19-25.

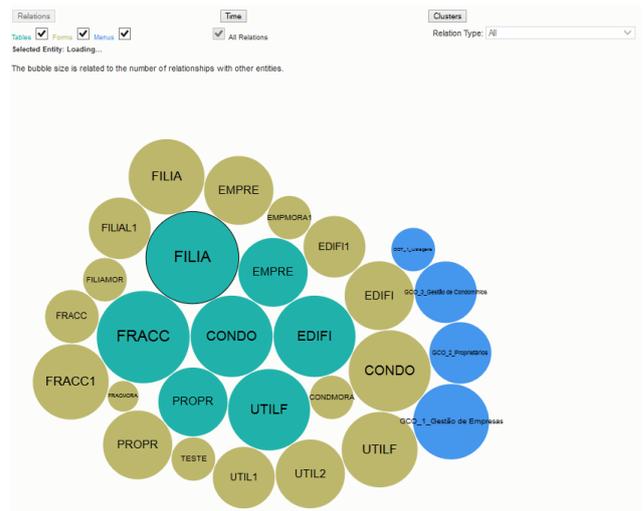
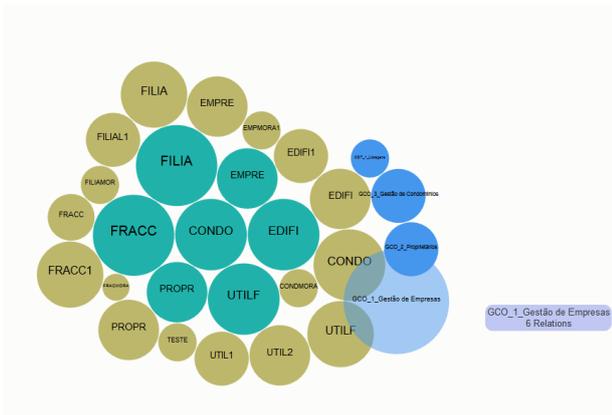
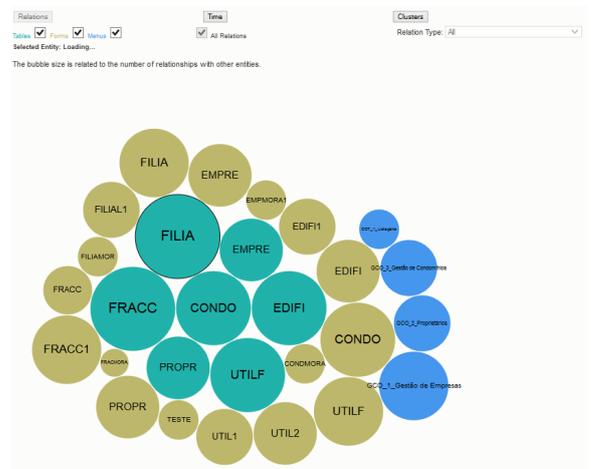
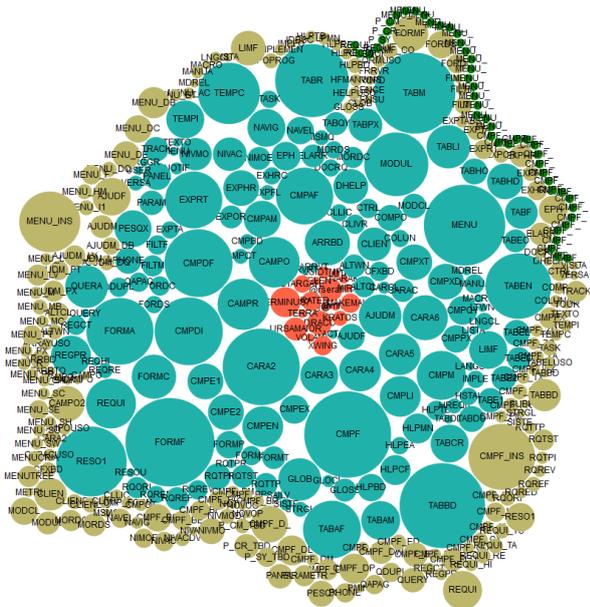
- [15] Kleppe, Anneke G., Jos B. Warmer, and Wim Bast. *MDA explained: the model driven architecture: practice and promise*. Addison-Wesley Professional, 2003
- [16] Gally, Matthias. "What is MDD/MDA and where will it lead the software development in the future?" (2007)
- [17] Kleppe, Anneke G., Jos B. Warmer, and Wim Bast. *MDA explained: the model driven architecture: practice and promise*. Addison-Wesley Professional, 2003
- [18] Soley, Richard. "Model driven architecture." *OMG white paper 308* (2000): 308
- [19] Sacevski, Igor, and Jadranka Veseli. "Introduction to Model Driven Architecture (MDA)." *Seminar Paper, University of Salzburg*. 2007
- [20] Mens, Tom, and Pieter Van Gorp. "A taxonomy of model transformation." *Electronic Notes in Theoretical Computer Science* 152 (2006): 125-142
- [21] Czarnecki, Krzysztof, and Simon Helsen. "Feature-based survey of model transformation approaches." *IBM Systems Journal* 45.3 (2006): 621-645
- [22] Sendall, Shane, and Wojtek Kozaczynski. *Model transformation the heart and soul of model-driven software development*. No. LGL-REPORT-2003-007. 2003
- [23] Breogán Gonda and Nicolás Jodal. "Knowledge-based Development: Philosophy and theoretical foundation of Genexus". Artech (2007)
- [24] Quidgest. "Genio E-book"
- [25] David Norfolk. "OutSystems Platform and Force.com different PaaS for different players". An InComparison Paper by Bloor Research (2013)
- [26] Johannes Bohnet, Jürgen Döllner: *Analyzing Feature Implementation by Visual Exploration of Architecturally-Embedded Call-Graphs*. 4th International Workshop on Dynamic Analysis, ACM, ACM Press, pp. 41–48, 2006
- [27] Petre, Marian, and Ed de Quincey. "A gentle overview of software visualisation." *PPIG News Letter* (2006): 1-10.
- [28] Aiken, Alexander, et al. "Tioga-2: A direct manipulation database visualization environment." *2013 IEEE 29th International Conference on Data Engineering (ICDE)*. IEEE Computer Society, 1996.
- [29] Stolte, Chris, Diane Tang, and Pat Hanrahan. "Polaris: A system for query, analysis, and visualization of multidimensional relational databases." *Visualization and Computer Graphics, IEEE Transactions on* 8.1 (2002): 52-65.
- [30] Storey, Margaret-Anne, et al. "SHriMP views: an interactive environment for information visualization and navigation." *CHI'02 Extended Abstracts on Human Factors in Computing Systems*. ACM, 2002.

- [31] Knight, Claire. "System and software visualisation." *Handbook of software engineering and knowledge engineering* (2001): 1-17.
- [32] Shneiderman, Ben. "The eyes have it: A task by data type taxonomy for information visualizations." *Visual Languages, 1996. Proceedings, IEEE Symposium on*. IEEE, 1996.
- [33] Upson, Craig, et al. "The application visualization system: A computational environment for scientific visualization." *Computer Graphics and Applications, IEEE 9.4* (1989): 30-42.
- [34] Bostock, M.: D3.js - data-driven documents. <http://d3js.org>
- [35] Dumas, Joseph S., and Janice Redish. *A practical guide to usability testing*. Intellect Books, 1999.
- [36] Brooke, John. "SUS-A quick and dirty usability scale." *Usability evaluation in industry* 189 (1996): 194.
- [37] Prat, Nicolas, Isabelle Comyn-Wattiau, and Jacky Akoka. "ARTIFACT EVALUATION IN INFORMATION SYSTEMS DESIGN-SCIENCE RESEARCH—A HOLISTIC VIEW." *18th Pacific Asia Conference on Information Systems, Chengdu, China*. 2014.

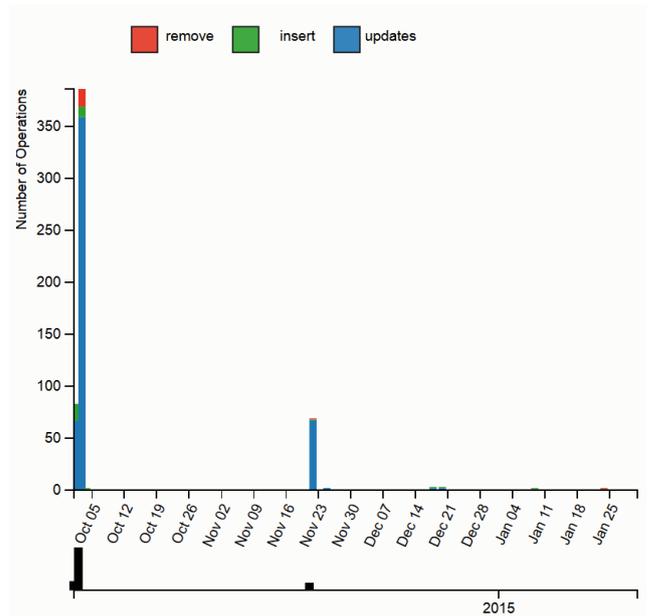
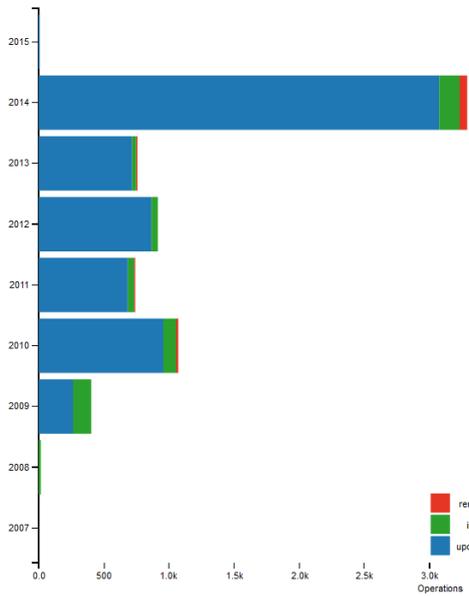
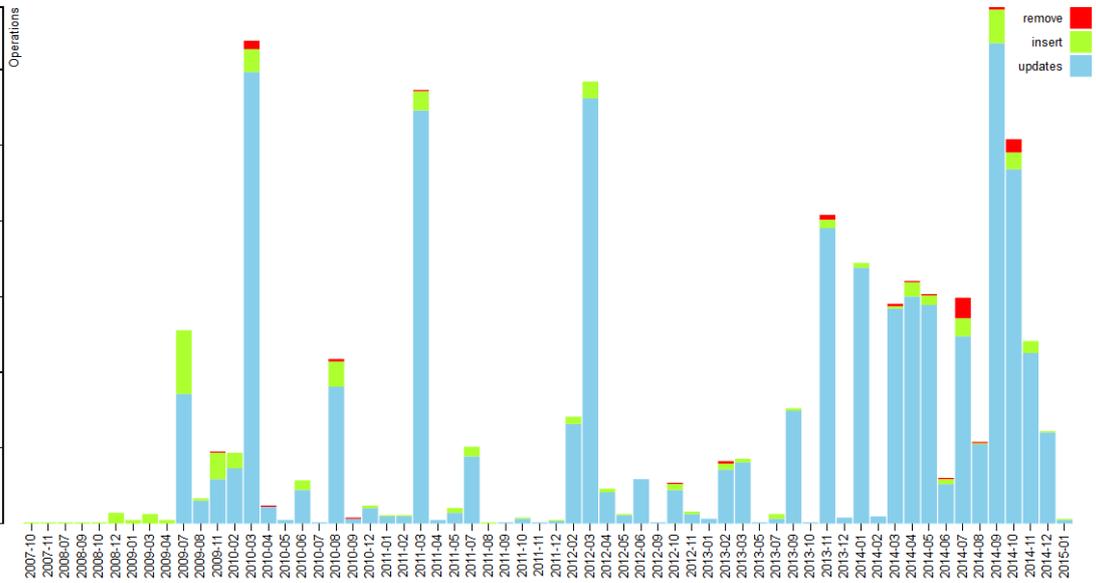
Appendix A – Prototype Evolution

In this appendix we present screenshots taken during the prototyping phase which represent the evolution of our prototype. Since the current version of the tool is described in the demonstration chapter, we didn't include it here.

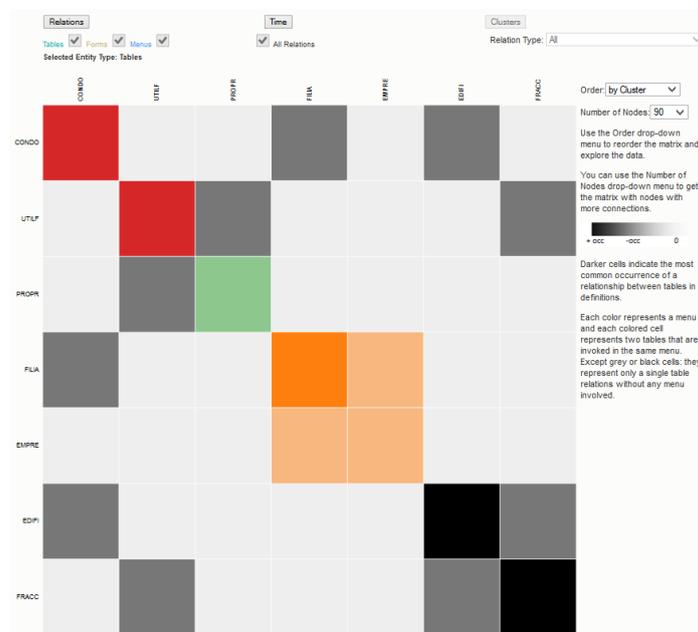
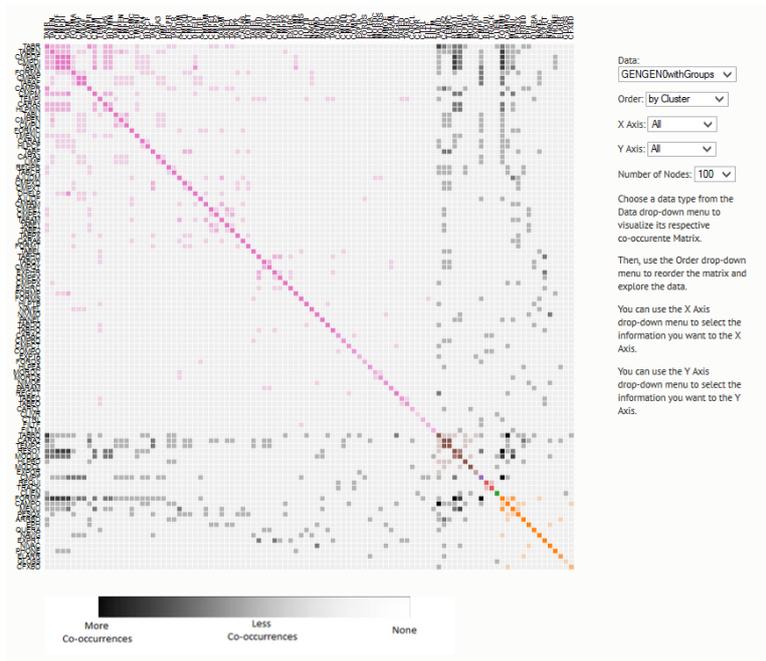
Objects decomposition



Time



Grouping



Appendix B – User Questionnaire

Questionário

Este questionário tem o objectivo de construir um perfil dos utilizadores e avaliar a usabilidade do visualizador de modelos desenvolvido no âmbito do projecto FirstSightModel.

Seguem-se algumas questões relativas à experiência passada pelo utilizador, de forma a conseguirmos construir uma análise quantitativa e qualitativa do mesmo.

O questionário é anónimo e o seu preenchimento não levará mais que uns minutos. Agradecemos a sua cooperação.

1. Qual o seu género? Masculino Feminino

2. Qual a sua idade?
 - Menos de 18 anos
 - 18 - 24
 - 25 - 30
 - 31 - 40
 - 41 - 50
 - 51 - 60
 - Mais de 60 anos

3. Assinale com um X a opção que acha que se adequa à experiência que passou ao utilizar a ferramenta (**1 – Não concordo, 5 – Concordo completamente**)

	1	2	3	4	5
3.1 - Usaria este visualizador frequentemente	<input type="checkbox"/>				
3.2. - Achei o visualizador desnecessariamente complexo	<input type="checkbox"/>				
3.3. - Achei o visualizador fácil de usar	<input type="checkbox"/>				
3.4. - Acho que iria precisar de apoio para utilizar o visualizador	<input type="checkbox"/>				
3.5. - Acho que as funções do visualizador estão bem integradas	<input type="checkbox"/>				
3.6. - Acho que existem muitas inconsistências no visualizador	<input type="checkbox"/>				
3.7. - Acho que a maioria dos utilizadores aprenderiam rapidamente a utilizar o visualizador	<input type="checkbox"/>				
3.8. - Achei o visualizador demasiado pesado	<input type="checkbox"/>				
3.9. - Senti-me confiante a utilizar o visualizador	<input type="checkbox"/>				
3.10. - Teria de aprender muitas coisas antes de conseguir utilizar o visualizador	<input type="checkbox"/>				

4. (Opcional) Tem alguma sugestão de modificação/melhoria do visualizador?

Obrigado pelas respostas!

Appendix C – Usability tests results

	<i>User</i>	<i>Cliques</i>	<i>erros</i>	<i>tempo</i>
<i>Task 1</i>	U1	0	0	1
	U2	0	0	1
	U3	0	0	1
	U4	0	0	1
	U5	0	0	1
	U6	0	1	3
	U7	0	0	1
	U8	0	0	1
	U9	0	0	1
	U10	0	0	2

	<i>User</i>	<i>Cliques</i>	<i>erros</i>	<i>tempo</i>
<i>Task 2</i>	U1	7	0	60
	U2	11	3	85
	U3	7	1	40
	U4	10	3	55
	U5	12	3	90
	U6	11	2	88
	U7	10	2	72
	U8	9	1	65
	U9	13	2	96
	U10	11	2	78

	<i>User</i>	<i>Cliques</i>	<i>erros</i>	<i>tempo</i>
<i>Task 3</i>	U1	6	2	38
	U2	4	0	30
	U3	5	1	39
	U4	4	0	25
	U5	7	2	50
	U6	4	0	36
	U7	7	2	40
	U8	5	1	39
	U9	4	0	28
	U10	6	1	42

	<i>User</i>	<i>Cliques</i>	<i>erros</i>	<i>tempo</i>
<i>Task 4</i>	U1	6	2	40
	U2	3	1	35
	U3	2	0	32
	U4	3	1	30
	U5	2	0	23
	U6	2	0	33
	U7	3	0	25
	U8	2	0	31
	U9	6	1	38
	U10	2	0	26

	<i>User</i>	<i>Cliques</i>	<i>erros</i>	<i>tempo</i>
<i>Task 5</i>	U1	10	1	40
	U2	6	1	24
	U3	3	0	17
	U4	6	1	45
	U5	7	0	38
	U6	6	0	33
	U7	8	0	30
	U8	6	0	26
	U9	9	1	32
	U10	5	0	22