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Visualisation environment for global software development management

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Abstract: Global software development (GSD) involves new challenges that need to be addressed when project managers have to make significant decisions such as task allocation, resource assignments, etc. Visualisation techniques can be useful as regards helping managers to process complex information and interpret the data shown. The main goal of this study is to describe a visualisation environment with which to support the decision-making process in GSD contexts. The environment contains a set of visualisation metaphors that can be organised in a hierarchical manner and which show both the information related to GSD projects and subprojects and the organisational context of companies and their corresponding factories. The DESGLOSA tool has been developed to support the visualisation of measures and indicators in GSD. The tool has been applied in one of the INDRA Company's GSD projects and two surveys have been conducted to validate the potential usefulness of the environment and its applicability in the company. The results of these surveys were that most of the participants agreed that the tool is useful and stated that they would be willing to incorporate this kind of applications into their daily work.

1 Introduction

The software industry has been greatly affected by globalisation, thus making it necessary for firms to adopt a new approach, which has had repercussions as regards the methodologies and management processes of software products [1]. Global software development (GSD) implies a series of well-known benefits and drawbacks, as is well documented in the relevant literature [2–5].

Its benefits include a reduction in delivery times and access to a highly-skilled work-force, in addition to proximity to customers and markets. However, there are problems related to the three 'C's' (i.e. Communication, Coordination and Control), which complicate the management of global software processes and may have a negative impact on quality and productivity.

A recent study that sought to discover success factors as regards GSD [6] has shown a changing trend: classic issues such as geography, time and socio-cultural aspects are currently no longer as important as they were since they have been alleviated by existing and emerging technologies [7, 8]. This has been confirmed in studies such as [9], and it has also been concluded that the team members' skills, the appropriate management of GSD projects and process maturity play an increasingly important role [6]. A co-located project usually has a large quantity and diversity of available information, and decision-making in a global development setting thus involves considerably greater complexity, as information from each of the factories and their corresponding subprojects has to be handled.

The above considerations suggest that managers who are involved in GSD projects may benefit from supporting tools when making critical decisions. These decisions could be related to work allocation, along with identifying problems related to quality or productivity in certain factories, or the selection of highly qualified staff, among others. This need to facilitate managers' decisions, which are made on the basis of using visualisation mechanisms to analyse a large amount of information, was one of the most important challenges of the ORIGIN (Intelligent Global Innovative Organisations) R&D project, which constitutes the context of this work. ORIGIN was set up by a consortium composed of five companies and two Universities in Spain whose aim was to create a conceptual, methodological and technological framework for the management and development of software in global contexts. To address this challenge we propose the use of three-dimensional (3D) visualisation based on suitable metaphors. The application of metaphor-based visualisation in Software Engineering is rooted in the need to make it less complicated to understand software-related issues. The use of visualisation metaphors allows a relationship to be established between every-day elements and these abstract software-related concepts. This relationship in turn serves as an aid towards a fuller understanding of the concepts.

Bearing all this in mind, this paper presents a visualisation environment in which to represent measures and indicators of quality and productivity in GSD. The environment takes visualisation metaphors as its basis, and these are organised in different levels of abstraction to allow GSD managers to

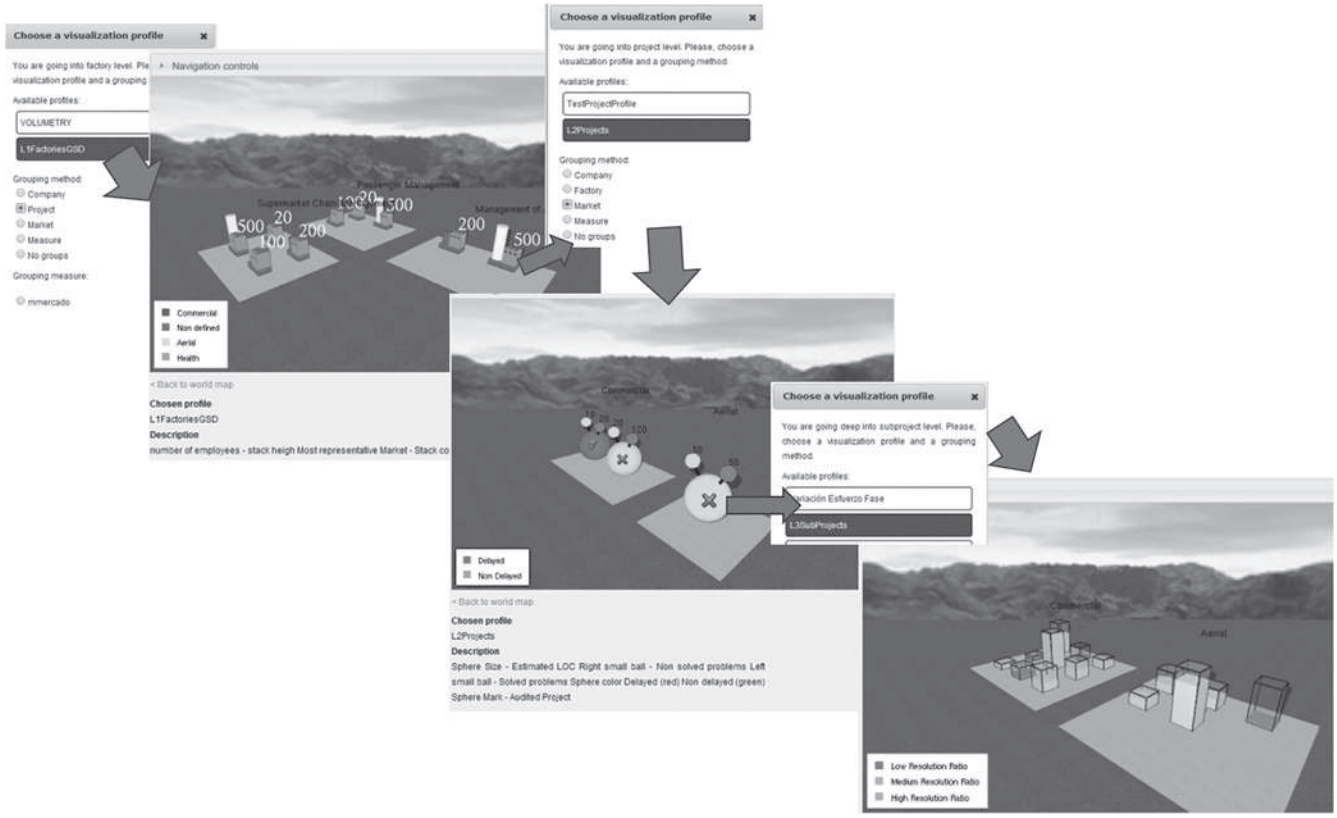

Fig. 1 *Visualisation Hierarchy of Metaphors: example*

understand and interpret the information better than if traditional graph-representation techniques were used. For instance, the tool can help managers to decide which factories will develop a new project. This assignment may depend on each factory's experience as regards the topic of the new project, on the number of projects and employees belonging to the factory (to take the workload into account) or on other attributes that the manager considers relevant. All this information can be shown using one metaphor, and the manager will have all the information needed to make a decision at a glance. When a project is already under development, the manager can use the tool to attain an overview of the execution of the project. The tool can also show indicators of quality and the productivity of a specific project. This is useful for team leaders who can obtain a vision of what is happening in the project. The visualisation of information can be personalised according to the needs of the project and the user profiles. The usefulness of the tool has been validated by applying the environment to an example case that is based on real-life projects being carried out at the INDRA Company, while two surveys were also carried out with representative samples of the firm's employees.

This paper is organised as follows: after this introduction, Section 2 presents the proposed visualisation metaphors, and their organisation into visualisation levels is also described. We then go on to provide a description of the DESGLOSA environment in Section 3. An example of its application in real-life cases in INDRA is provided in Section 4, whereas in Section 5 we provide details of the surveys conducted to assess the proposal's applicability in real settings. Section 6 analyses the state-of-the-art and the contribution of this proposal; and finally, our conclusions and future work are set out in Section 7.

2 Proposal for the visualisation of GSD quality and productivity indicators based on a hierarchy of metaphors

As pointed out in the Introduction section, the aim of the tool is to provide support for both the organisational management of GSD and the visualisation of relevant information, the latter of which might include the geolocation of the factories at which different parts of the project are undertaken, or a graphic representation of different measures and indicators of software quality and productivity. These measures and indicators will correspond to the information that is considered relevant, such as productivity, number of employees or the specialised market for the software factories. The tool visualises the data from a database that are periodically updated. As a part of the tool requirements, data are not therefore shown in a real-time mode but rather in several snapshots as required by users.

To show the information relating to measures of quality and productivity we propose the use of visualisation metaphors, which are made up of a set of graphic elements, such that each model has multiple properties called 'dimensions'. We opted to perform the visualisation on three levels (see Fig. 1):

- *Industrial area (factories metaphor):* This consists of a graphical model of the factories, shown in the form of traditional industrial factories, which together make up an industrial estate. The model depicts a factory that has a base upon which there is a building and a smokestack. The dimensions of this model will be the scale of the factory (global size), the colour of the smokestack and its height.

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• *Project and subproject visualisation (sphere metaphor):* The lack of a metaphor that would come close to representing the concept of a project led to the design of this model, which seeks to meet the visualisation needs outlined by the experts in the sector. The structure of the sphere metaphor contains a bottomsphere, the colour and shape of which may vary. This has a space reserved within it for a mark, which may be either an icon of a green tick or a red cross. Each sphere has two 'antennae', both of which have a small sphere at the end. These small spheres are red and green, respectively, and each shows a whole number above it. Lastly, a text chain is displayed under the bottom sphere.
• *Towers (city metaphor):* Each tower represents a structure similar to a skyscraper (based on [10]). The scene depicts a city in which each district represents data that are grouped by project, market, etc. This model was designed to be specifically tailored to any given entity and then to represent it in a generic sense. The dimensions in each tower are the width, depth, total height, height of shading (inner height) and colour.

It should be noted that these metaphors may be applied to any entity -that is, one single entity- (such as a project), which can be visualised using different metaphors. The user can define visualisation levels and is able to navigate properly between them. As an example, the user may first need to obtain an overview of his/her factories, and this will allow him/her to gain access to the projects that are being undertaken in each one of them and thus keep track of the progress of these projects. What is more, in a GSD context it may be more appropriate to visualise the projects in which the company is involved in a first level and then focus on particular factories or subprojects in subsequent levels. To meet this need, a solution is proposed in which the user could navigate between the different visualisation metaphors by means of a hierarchy of visualisation profiles and choose the particular graphical models that he/she wishes to consider (see Fig. 1).

3 DESGLOSA-GSD

The objective is that Desglosa-GSD will be an 'intuitive' web application and it has been developed with JAVA technology for the visualisation of indicators in a GSD context. The visualisation in this environment needs to be flexible, thus allowing users to configure the visualisation type that best suits them, and it should also be extensible to permit new visualisation metaphors to be added quickly and easily. The tool is accessible for the following roles:

• *Administrator:* This is an expert user of the system, with complete control of all the functionalities, who is in charge of managing the configuration tasks of the companies and factories in the system, along with visualisation profiles.
• *Project Manager:* This system user's job consists of looking after the configuration of the projects and subprojects he/she leads.

The tool permits Administrator users (visualisation experts) to choose which metaphor to employ for the representation of the information of a particular entity (company, factory, project or subproject). The user can then configure associations between the different characteristics of the entity (its name, different measures or indicators and so on), in addition to the dimensions of the graphical model. This means that the display will vary, depending on the values

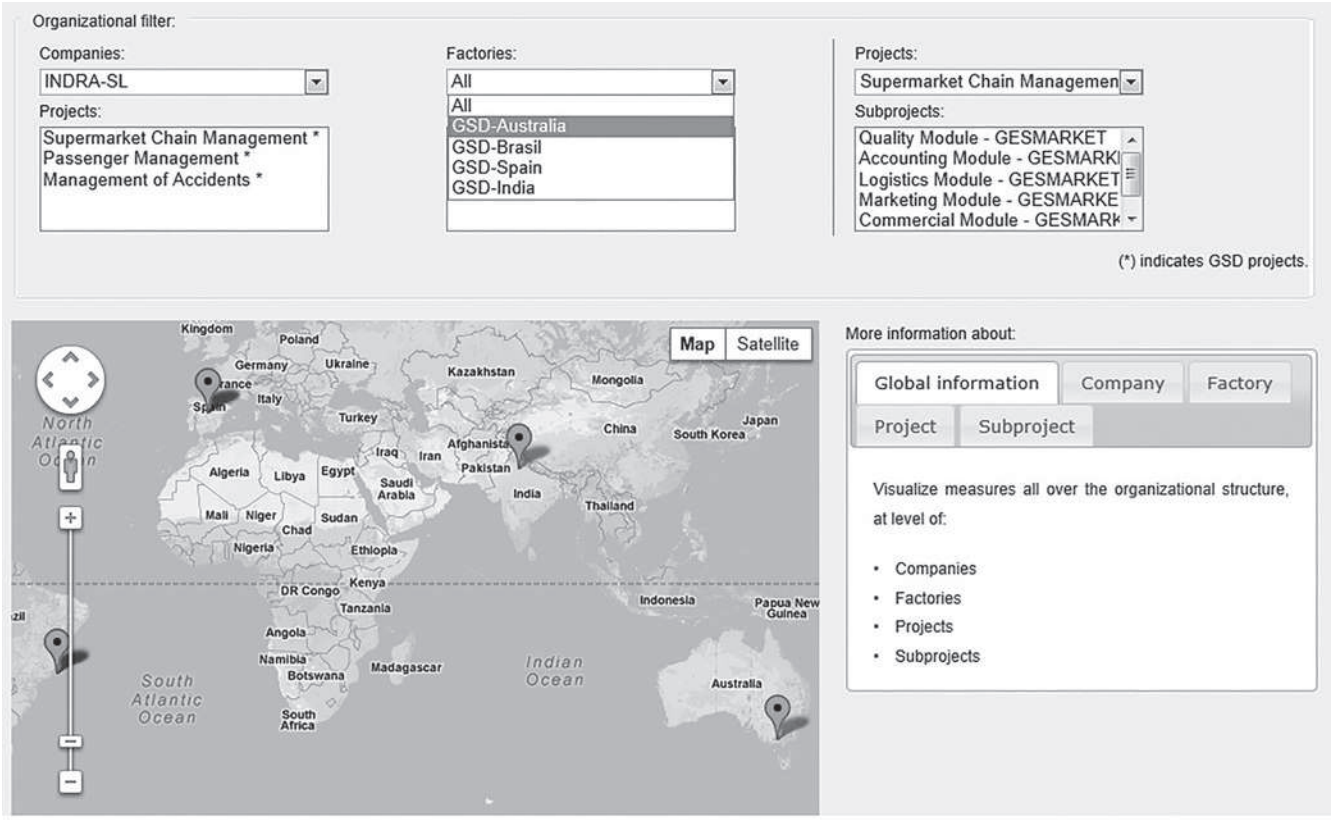


Fig. 2 *Overview of the company and factories in the application example*

that are stored by the entity's attributes. The administrators' expertise in visualisation allows them to tailor the visualisation, and they are therefore responsible for choosing the best metaphors for each project according to the users' requirements. These users are expected to know the characteristics of each metaphor and thus interpret the visualisation results correctly. The tool also displays extra information to support a better understanding, such as the explanation of the meaning of each dimension in the metaphor. The objective of these mechanisms is to facilitate the interchange of information and a common understanding of visualisation among project stakeholders.

The main functionalities of DESGLOSA-GSD are:

- *The management of companies, factories, projects and subprojects:* These functionalities allow the administrator to create, eliminate and modify information about the companies and their factories, along with that concerning the projects that are being carried out in the companies and the subprojects that are being undertaken in each of the factories. The system enables information that is relevant to the user to be shown, and selection filters have been applied to these elements (see Section 4, Fig. 2). The geolocation of each factory is also displayed on a map.
- *The management of visualisation profiles:* This encompasses the functionalities of creating, consulting and eliminating visualisation profiles, and these profiles configure the desired information in each metaphor, showing it in 3D graphic form. The user can choose the measure or indicator to be shown, in addition to the attribute of the metaphor with which it will be represented. For instance, the size of a factory (an attribute of a graphical model), can represent the number of employees at that factory (a measure that is of interest). The ranges of values can also be selected to facilitate an appropriate scaling of the visualisation.
- *The visualisation of measures and indicators:* This is the main functionality of the tool, and permits the user to visualise the relevant information of an entity (company, factory, project or subproject), according to a given visualisation profile. The user can similarly choose the grouping mode, that is, the user decides the meaning of each of the districts (which may be classified according to the company, factory or project, among others). Once the user has gained access to the particular scene that is brought up in the visualisation, he/she has the possibility of navigating around that scene (moving the camera around, rotating it, focusing on particular objects, etc.). Each time an element is chosen, the system shows the user some information about the element selected and allows him/her to visualise the information related to the element by means of a visualisation profile (small red arrows in Fig. 1). For example, if a factory in the metaphor of the industrial estate is chosen, its profile will be used to show information about only that factory (projects and subprojects in which the factory is involved). In this case, the user is gaining access to a new level of visualisation (blue arrows in Fig. 1).

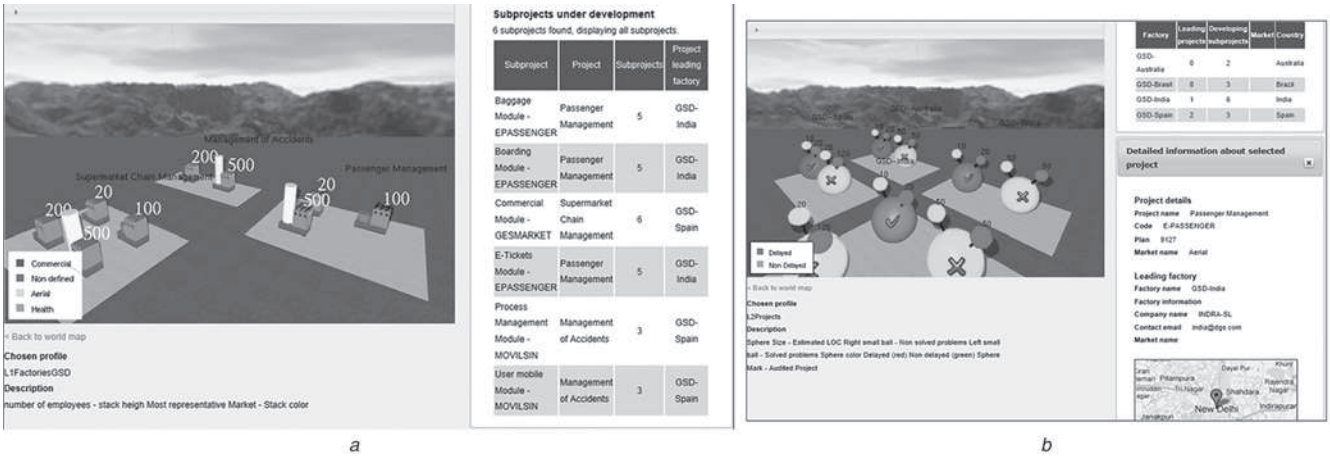
The following sections provide descriptions of how the tool was validated (using an application example) and two surveys, respectively.

4 Application example of DESGLOSA-GSD

In an attempt to obtain an initial insight into the validity of the tool in real environments, an application example was designed based on real projects being carried out at INDRA, that is, the Indra Software Labs (ISL). ISL is a subsidiary company of the INDRA group, which specialises in software development and is composed of 9000 professionals in 21 factories, distributed throughout several countries such as in Europe, Africa, the USA and Asia. The company's volume of sales has been increasing over the last few years, mainly as the result of the positive evolution of the international market, and this situation highlights the significance of GSD in the company.

The data that are visualised in this example are fictitious to preserve their confidentiality, but they are representative of GSD projects since they were inspired by actual records from the project. This example is that which is included in the demo of the tool, a video of which was watched by the professionals who participated in the first survey (see Section 6). The example consists of visualising the global projects carried out at INDRA, and more precisely at fictitious factories located in Brazil, Australia, India and Spain (Fig. 2).

The work allocation mode in the application example is 'by modules' and the projects that are being developed globally are:



a b

Fig. 3 *Scenes of the application example*

a Industrial area scene of the application example
b Project scene of the application example

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• The Management of a Supermarket Chain, which is composed of six modules allocated as follows: two in Spain, two in Brasil, one in India and one in Australia.
• Passenger Management, which includes five modules (three in India, one in Brazil and one in Australia).
• Accidents Management (Insurance Sector), which is composed of three modules (two in India and one in Spain).

The visualisation defined was organised in three levels (thus allowing the user to navigate freely around the scene):

• *Level 1. Factories Metaphor:* The number of employees in the factory is represented as the height of the smokestack, while the market in which the factory specialises is represented by the colour of the stack. Each district groups together the factories that are developing each project (Fig. 3*a*). The visualisation is complemented by the textual data, which is shown on the right of the element selected in the scene.
• *Level 2. Sphere Metaphor (Project Visualisation):* The aim of the scene is to show certain characteristics of the GSD projects that are being developed in different factories (Fig. 3*b*). The measure mapping with graphical elements is: Sphere Size – Estimated Lines of Code in the project (obtained after conversion of estimation of Function Points); number over the small sphere on the right-hand side – non-solved problems; number over the small sphere on the left-hand side – solved problems; sphere colour: delayed (red); non-delayed (green); sphere mark – the project was audited in the company (this is a special characteristic in the INDRA projects). Each district represents a factory, and the spheres are therefore the projects in which the factory is involved. When the user clicks onto a sphere, the panel on the right shows detailed information about the element selected.
• *Level 3. City Metaphor (subproject visualisation):* This metaphor was chosen to represent characteristics of the subprojects. It is important to highlight that the term 'subproject' in the context of this example is used to mean the development of each module by the factories. Two scenes were created:

o *Scene 1:* This shows the issue management process of the factory in the project (Fig. 4). The mapping was: height of the tower – total number of problems discovered; inner Height (filled-in area in each tower) – number of problems solved; colour – resolution ratio on a scale composed of three colours (red, orange and green).
o *Scene 2:* This shows the quality subcharacteristic of maintainability, the value of which is collected along with the other quality characteristics, according to the classification provided in the ISO 25010 standard. As a result, the company also gives a score to the total quality. In this case, the mapping was: inner height (filled-in area) – maintainability and colour – quality ratio. the height, width and depth of the tower were given constant values.

In this example, the hierarchy of visualisation was organised into the levels of factory, project and subproject, respectively, but it is important to stress that the user is free to select the entity that he/she wishes to consider in each level, and can use the 'organisational filter' combo lists for this purpose (see upper part of Fig. 2).

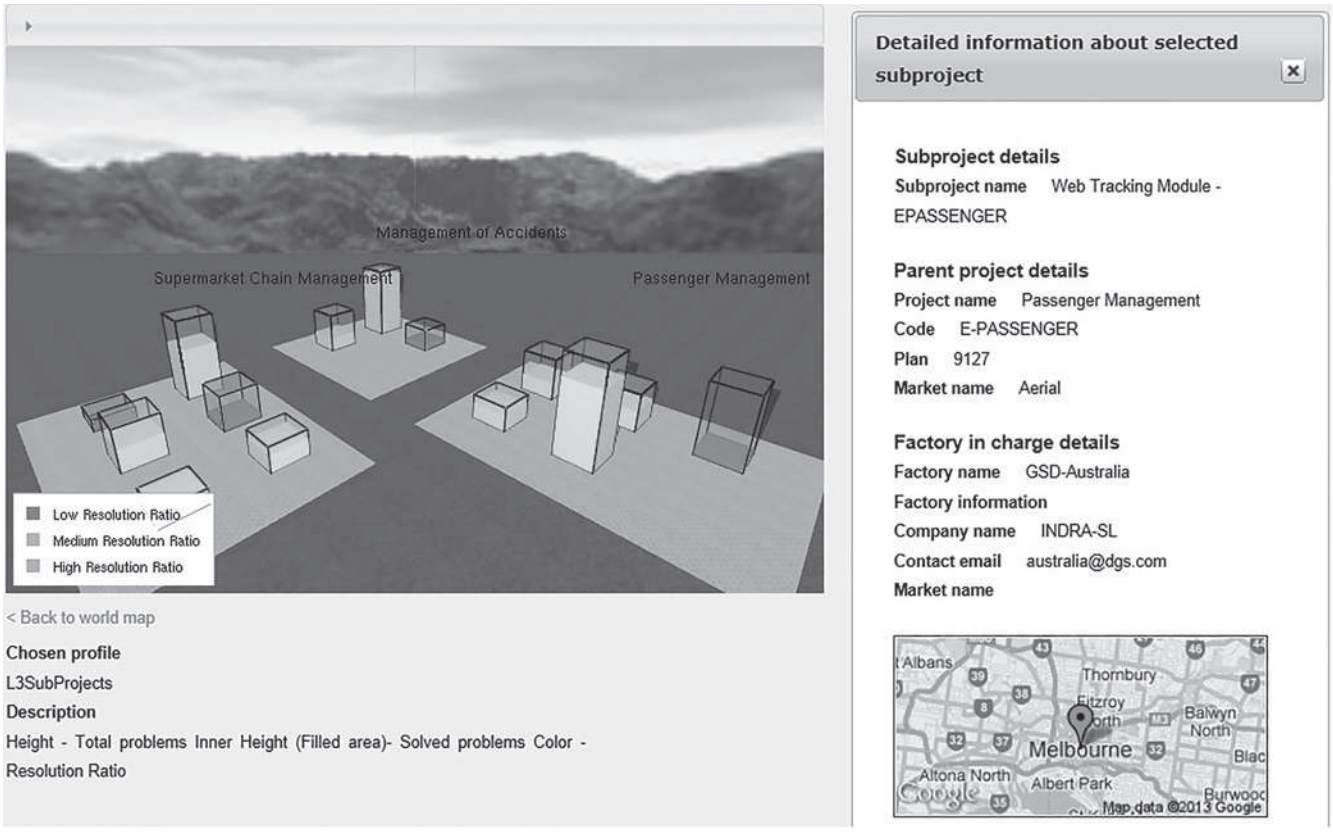

Fig. 4 *Subproject scene of the application example*
Problem resolution visualisation

As a result of the development of the application example, we concluded that it was possible to apply the tool properly to represent the example case, which is based on real scenarios in INDRA.

5 Exploratory analysis of DESGLOSA application in GSD environments

To test the feasibility of using DESGLOSA in real settings, a preliminary validation was conducted which was composed of two main phases: a first phase in which a survey was conducted with 22 practitioners from INDRA software company. The recommendations and feedback obtained were used as the basis to enhance the DESGLOSA tool, and a second survey was then sent to six highly skilled software managers in the company who used the tool with a representative example. Detailed descriptions of these stages are provided in the following subsections.

5.1 First stage: initial survey

A survey was carried out to validate the DESGLOSA environment and the visualisation metaphors it contains. Starting from the results, the applicability of the tool was analysed before it was handed over for use in the company. The survey was put together by following the specific steps and recommendations of [11–16]. Special attention was therefore paid to the selection of the questions that appeared. These were formulated in such a way that respondents could answer them easily and accurately, and they were purposeful, concrete and closed. We bore in mind that the number of questions should be adequate (not too many). With regard to the questionnaire format, we left a space to allow the participants to provide a comment for each question, and used spaces between questions, boxes, etc. to maximise the clarity of questions.

We carried out a non-supervised survey in which a researcher does not need to be on hand to deal with queries. The research questions were:

- *RQ1:* Is the graphical visualisation useful?
- *RQ2:* Is the choice of metaphors and their organisation adequate for GSD projects?
- *RQ3:* Are the visualisation metaphors appropriate?
- *RQ4:* Should the tool be customisable?
- *RQ5:* Is the tool easy to use?

We shall now go on to present the steps followed to conduct this survey in a satisfactory manner.

5.1.1 Survey design: The questionnaire was designed using a prototype that was a kind of self-control study. After the users had seen a demo-video about the DESGLOSA tool and the metaphors used in it (which were illustrated in Section 4), they were asked questions about what they had seen.

5.1.2 Sample size: The next step was to determine the sample. We knew that the survey population we were studying would be made up of the participants in the ORIGIN project – about 60 subjects, and we therefore used a non-probabilistic sampling method to establish the sample. As a result, we obtained a sample made up of 22 people, all of whom answered the questionnaire.

5.1.3 Constructing the survey instrument: In drawing up the questions, the purpose and objectives of the survey were borne in mind, thus allowing us to ensure that the questions were directly related to the survey's objectives. The following factors were also taken into account when deciding what to ask: (a) the questions needed to be worded in such a way that those answering could do so easily and accurately; (b) there had to be an appropriate number of questions; (c) the answers needed to be standardised using the following ordinal scale: 1: Totally disagree, 2: Disagree, 3: Neither agree nor disagree, 4: Agree, 5: Totally agree.

To produce the questions we realised that they had to make sense and that they needed to be specific. The language used was therefore conventional, using terminology that would be familiar to the participants, and negative questions were not included.

All the questions were of the closed-type, that is, the participants had to choose one of the answers provided, and we also included an additional question with a blank space in which participants could make observations. We also incorporated some questions at the beginning of the questionnaire which were related to demographic characteristics (the participant's gender, age and experience, along with the department in which he/she worked).

Moreover, as the questionnaires were non-supervised, it was important to take into account both the format of the questionnaire and the instructions that were provided to carry it out properly. To that end, before asking the survey questions we incorporated some instructions on how to fill in the questionnaire (see Appendix 1).

5.1.4 Questionnaire evaluation: After carrying out the above steps, the questionnaire then had to be assessed. This was done by bearing the following points in mind [13]:

- The subjects of the survey must be motivated.
- Partiality on the part of the person conducting the survey must be avoided, or at least minimised.
- The questionnaire has to be assessed formally. This was done by carrying out a pilot study in which an expert was given the questionnaire; he answered and checked it and then provided us with feedback in the form of a series of suggestions which were used to improve the quality of the survey (specifically, the understandability of certain questions).

All the information related to the survey that was carried out is presented in this section and Appendix 1.

5.1.5 Data analysis: Once the survey had been carried out, the final step consisted of analysing the results obtained. The survey was distributed to 22 people in all, with a response rate of 100%. The survey's reliability was first tested using 'Cronbach's Alpha', and a value of 0.9 was obtained. This value is appropriate since it is over 0.7, the threshold above which the reliability of results is assured. Having proven the reliability of the survey, the profile of those surveyed was established. The majority of the participants were male, with an average age of 36. They were seen to have a wide experience in quality management in general (8.7 years, on average) and also in global software projects (5.7 years, on average). The next step was to analyse the results obtained for each of the questions asked with regard to the tool and the visualisation metaphors. The questionnaire was made up of a total of 31 questions, divided into 7 sections which we shall call dimensions: General, GSD Visualisation, Visualisation

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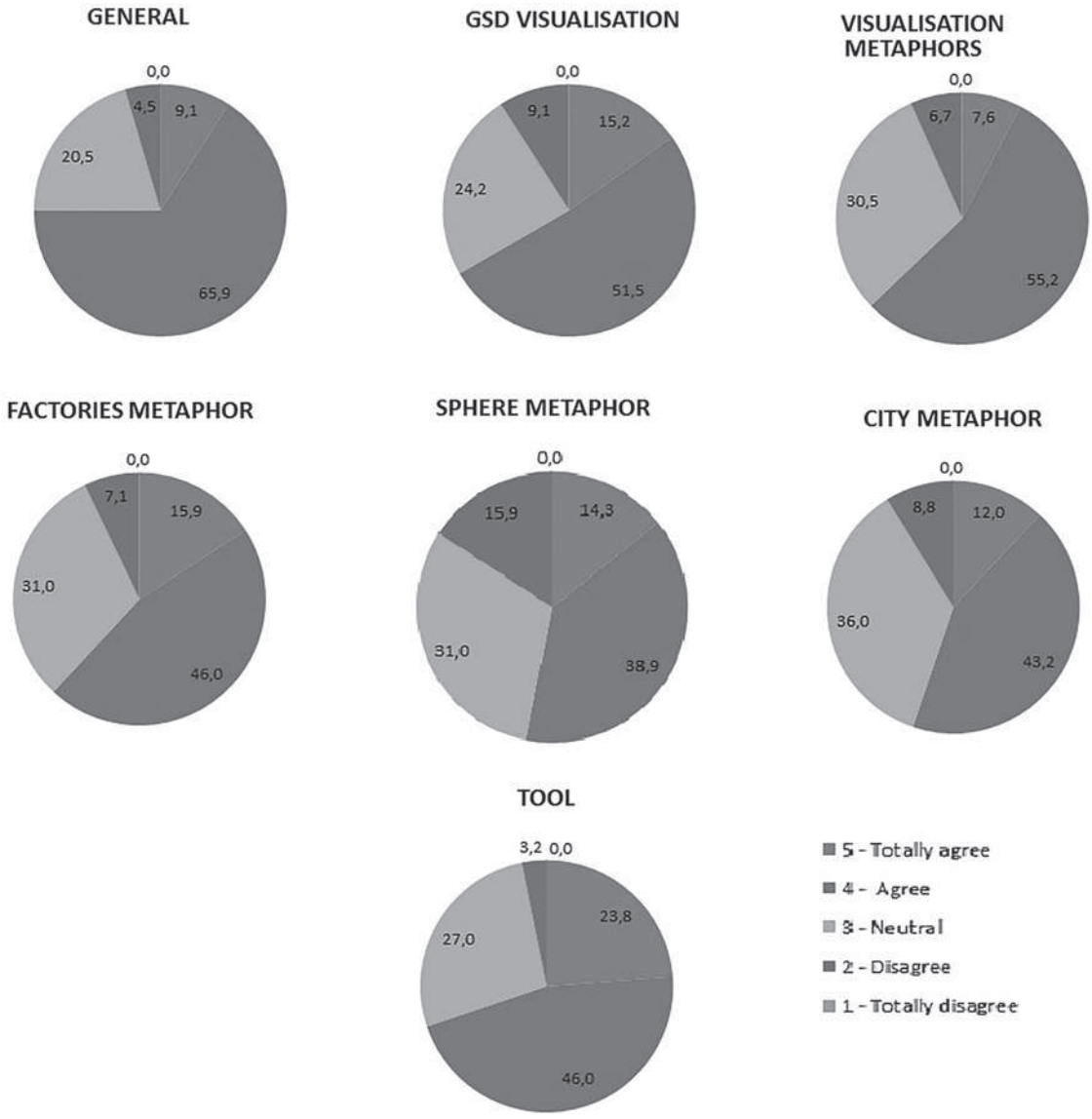

Fig. 5 *Frequencies for each dimension in the survey*

metaphors, Factory Metaphor, Sphere Metaphor, City Metaphor and The Tool. Fig. 5 presents the analysis of the results by dimensions.

Fig. 5 shows the results of the survey classified by dimensions. The majority of the participants considered that all the aspects under study were positive (they agreed or totally agreed with the survey questions) for all the dimensions. A more detailed analysis of the information shown in Fig. 6 reveals that:

- In the **general dimension** (questions Q1–Q2), the participants considered that it is better to have graphical visualisations than textual displays (91% of the participants were either in total agreement or in agreement). In fact, the participants considered that it is better to use metaphors than traditional graphs. (60% of the users agreed). All the percentages are shown in Fig. 6.
- In the **GSD visualisation dimension** (questions Q3–Q5): between 60 and 77% of participants totally agreed or agreed that the visualisation offered by the tool improves the interpretation of the indicators in comparison with classical representations; they also agreed that it is necessary to visualise the indicators using different levels and that the metaphors should vary depending on the information being displayed.
- In the **visualisation metaphors** (questions Q6–Q10), the participants agreed or totally agreed that the interpretation of the result is easier if you can navigate around the scene (62%) or can go from one level to another, choosing an element of the metaphor (66%). However, there was not a similar consensus as regards the suitability of the metaphors used. Of the three metaphors used in the tool, two of them (the factory metaphor and the city metaphor) produced good results, but in the case of the sphere metaphor only 43% of the participants totally agreed or agreed that it was suitable, whereas 47% of the participants neither agreed nor disagreed. This metaphor should therefore be improved in future versions.
- **Specific metaphor dimensions**. We asked about the factory metaphor (Q11–Q16), the sphere metaphor, (Q17–Q22) and the city metaphor (Q23–Q28). For all the metaphors we asked whether: the metaphor is natural, understandable, the quantity of information it contains is appropriate, allows us to draw conclusions easily, the default colours used are appropriate and whether it is important to be able to move around the scene to avoid

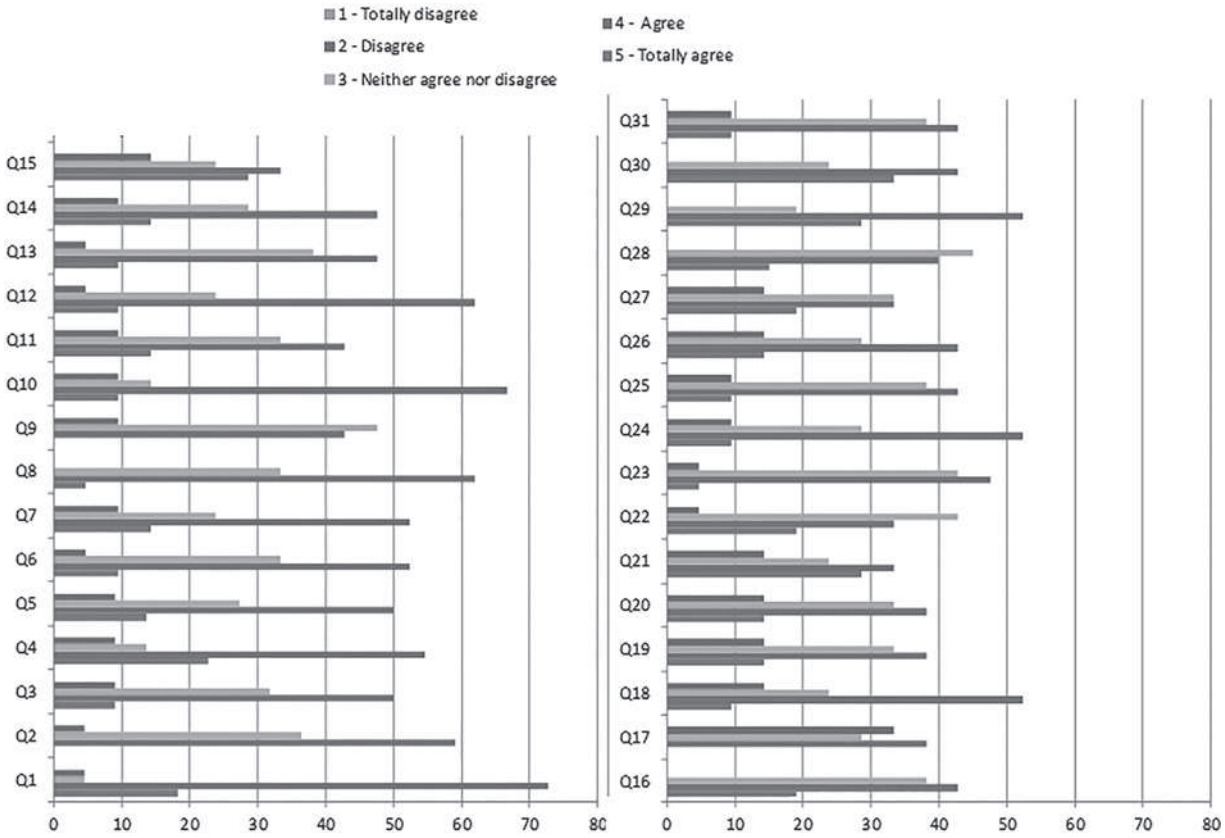

Fig. 6 *Percentages for each response*

mistakes in the interpretation. The factory metaphor obtained the best results; whereas the sphere and city metaphors obtained similar results. The worst result was for the sphere metaphor in relation to the question about whether it was natural. Only 38% of the participants agreed that it was natural as opposed to the 33% who disagreed. This finding is owing to the lack of a similar element in the real world. However, the sphere metaphor obtained good results in the other questions.

- **Tool dimension** (Q29–Q 31). Most of the participants (81 and 71%) agreed or totally agreed that it is important to be able to configure which graphic element corresponds with a particular indicator, and that the user should configure the visualisation levels and the metaphor to be used in each one, respectively. With regard to whether the tool is easy to use, 52% of participants agreed or totally agreed that it is easy to use, whereas only 9% disagreed or totally disagreed.

One conclusion that it is possible to draw from an analysis of the results of the survey carried out is that most of the people who took part in the survey considered this type of tool to be useful. They believed that it could be of assistance in their work, in the context of evaluating product quality in GSD. The participants considered the following to be positive: the way in which the tool tackles its task with the separation into different hierarchical levels, the different visualisation metaphors with several indicators shown in one single display, the customisation of levels and metaphors, and the possibility of choosing the metaphors. The evaluation we received of the sphere metaphor was fairly moderate, and this metaphor may therefore need to be analysed in detail in an attempt to make it seem more similar to a particular real-life element.

5.2 Second stage: final survey

The results obtained in the first step led to some interviews being conducted to collect new requirements with which to enhance the tool. The main new requirement was the possibility of supporting the grouping of results in districts not only according to the company, factory or project but by also considering other possible variables of interest such as the market, the country or the programming language. This resulted in the release of a new version of the tool which supports the groupings by any variable whose type is Boolean, String or Numeric. Another significant aspect that was addressed in the second stage was that the respondents actually used the tool to do the application example before answering the survey (the survey is shown in Appendix 2).

This new release was applied in a second validation stage by 6 software managers in INDRA who work with indicators concerning project estimation, requirements, quality, productivity and testing. The survey was conducted by following the same research method as in the previous stage, but the main findings will be summarised here for the sake of simplicity.

Fig. 7 shows that none of the participants totally disagreed with any of the question. In fact, only one participant disagreed with three questions (Q2, Q4 and Q7). This indicates that, in general, the participants agreed with the aspects of the tool that we asked about in the survey. Upon performing a detailed analysis for each question, the main results are the following. The majority of the participants agreed with questions Q1–Q9. Questions Q1–Q4 were focused on the use of metaphors, the navigation around the scene and the different levels of visualisation. The vast majority of the participants (83% for Q1, Q2 and 100% for Q4) agreed or totally agreed with these aspects. Questions

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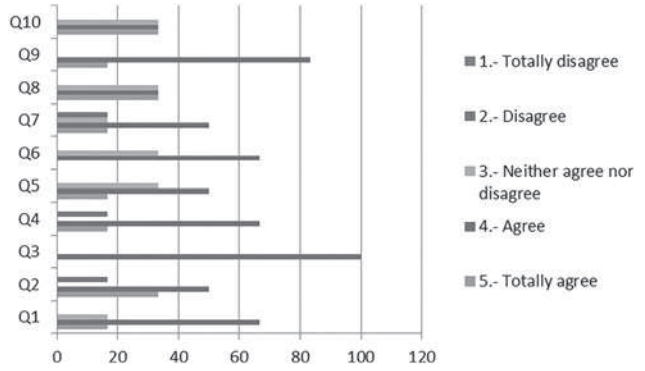

Fig. 7 *Percentages for each response (Survey 2)*

Q5–Q7 were related to the usefulness of the metaphors proposed in the tool. As a result we have obtained that 67% of participants agreed or totally agreed with the usefulness of the metaphors. The worst result was obtained for the city metaphor since one participant disagreed that it was useful. With regard to Q8 and Q9, 67 and 100% of the participants, respectively, agreed or totally agreed with them. These questions are more focused on the possibility of adapting the tool to the specific needs of each case. Question Q10 obtained the same values for the scales 3, 4 and 5. This question concerned the usefulness of the tool as regards making better decisions in a GSD project, and this result therefore indicates that the tool is really useful. A total of 67% of participants agreed or totally agreed with this affirmation.

5.3 Threats to validity

Various recommendations have been followed in the design and production of the survey, in the quest for maximum rigour and precision. There were, however, some limitations or threats to validity. In the first place, in spite of the fact that the sample was as heterogeneous as possible it must be recognised that all the subjects belonged to the same organisation, signifying that it will be necessary to carry out new surveys with the personnel from different companies in the future. Although the results may be different, we believe that they will also find the tool useful. However, these outcomes must be tested. Another threat to validity that we have detected is the scalability of the data. The surveys were carried out by designing two small examples. Although the examples were not too complex, they did serve to illustrate the tool's behaviour. It should also be noted that both examples are sufficiently representative of an actual GSD project at the Indra Company, since only four or five factories at the most are usually involved in a software development project. We thus consider that the examples are sufficiently representative to fulfil the purpose of carrying out the survey, although we are planning to design a larger and more complex system in the future.

It should also be noted that another threat to validity is the sample size. In the first survey, although the number of people surveyed was not particularly high, the population that the tool is designed for is not excessively large. This means that the size of the sample can be considered as acceptable and representative as regards achieving the goal in our survey, that is, to validate the usefulness of the tool and the metaphors used.

In the case of the second survey, the sample size is smaller and this is therefore the principal threat to its validity. We are aware that this may have affected the validity of results, but the difficulty involved in finding highly skilled managers in GSD projects must be stressed, and these results are consequently encouraging and can be considered as a good starting point for a future replication in which the potential applicability and usefulness of DESGLOSA in real settings will be tested.

With regard to the threat to validity of data Visualisation, we principally used the city metaphor as it has been successfully used in other tools such as Citilizer, which have been validated in [17–21]. What is more, to tackle the special needs of GSD, we also added representations in the forms of spheres and factories. To improve the capability to generalise the results of these two new metaphores further validation should be conducted in more industrial contexts.

6 Related work

There are a host of approaches in the visualisation field, among which we could highlight the basic ones described in [22]: bar charts matrices [23], landscapes, networks [24], dot-plots, histograms, data sheets [25, 26], paraboxes [27] and timetables. The last few years have witnessed the appearance of various advances in many visualisation-related issues, and fresh visualisation techniques and their application to new environments have been proposed.

6.1 New visualisation techniques

With regard to improvements in visualisation techniques, Agrawala *et al.* [28] identified the main design principles for visual communication, proposing a methodology with which to identify, instantiate and evaluate visual design principles for specific domains. Burkhard and Meier [29], meanwhile, suggest a new visualisation technique based on the underground railway map known as Tube Map, while da Silva *et al.* [30] proposed the use of Cockpits for the visualisation and coordination of distributed software development. It is worth highlighting the Code_swarm system [31], an organic visualisation technique which seeks to display information about the development of a project, Metaballs [32] which aims to ease program comprehension by using 3D enhancing balls, and CodeTrees [33]. Lastly, we should mention the improvements in visualisation that are based on cities, such as those proposed by [17–21].

6.2 Visualisation in software development

In the field of software evolution, it is worth mentioning VRCS [34], a 3D system aimed at developers and maintainers to allow them to analyse the different versions of a particular software, Release History [35], which is a 3D software structure evolution system based on VRML, EPO (see [36]) a 3D visualisation system to show the dependencies between software components, and SME [37], which uses an interactive differential and temporal approach to visualise software evolution. Last of all in this overview, we should mention the city metaphor found in [10, 21], and Code_Swarm [31] whose principal objective is to represent evolution in the development of a software system.

In the area of software requirements analysis, we should draw the reader's attention to systems such as ReqViz3d [38] for the display, validation and understanding of

requirements, along with ScenarioML [39], which model scenarios and display cross-project transitions. The visualisation of requirements in distributed environments has been tackled in work such as that of ReBlock [40], a tool that uses pyramids to represent requirements information.

It is in design and software maintenance that most headway has been made as regards visualisation, since this is generally where there has been a greater sense of the need to visualise software systems. This is because these systems tend to be really large, making it necessary to use visualisation systems to be able to manage them properly. Some examples of these systems are Geons3D [41], CodeMapping [42], TraceCrawler [43], X3D-UML [44], Vizz3D [45], Citylizer [18], Tulip 3 [46] or World View [47].

6.3 Visualisation of global software development

There have been few real breakthroughs in this area of visualisation of GSD because the majority of systems are based on the portrayal of large-scale systems. The work that may be found in this context is, for example World View [47], which proposes the display of development on a world map, along with Ariadne and TraVis, which support the automatic analysis of dependencies, visualisation of social dependency information and the display of traceability [48]. Another stream of research in visualisation which may be useful in GSD contexts is related to tools that provide an awareness of human activities in software development [49] such as SecondWatch [50] and ProxiScientia [51].

In short, work on visualisation in GSD has focused on aspects of coordination and traceability; there is no solution that would make it possible to visualise quality and productivity indicators with flexibility and in which the necessary attention is paid to users' preferences. In our work, we have proposed a system that seeks a synergy by using several of the techniques already mentioned, such as Citylizer or World View, alongside a proposal for new visualisation metaphors for GSD. The aim is to produce an integrated visualisation system that would be of assistance to global project managers, thus helping them to administer such a highly complex undertaking appropriately.

In summary, the main innovation as regards the contributions of the proposal in relation to existing visualisation tools is that DESGLOSA provides managers with a visualisation environment that is focused on quality and productivity in GSD, which includes new metaphors to assist in the visualisation (factories and spheres) and adapts the city metaphor for its application in GSD. This visualisation is, moreover, organised in a hierarchy, and visualisation can be customised according to the final users' preferences and profiles.

7 Conclusions

In this paper, we have proposed a tool that aims to visualise the data management of GSD using metaphors. This reduces complexity, both in understanding data and in global project management, which in turn means that managerial decision-making is supported. The DESGLOSA-GSD tool has been presented here as a 3D visualisation web application which focuses on presenting global development software project data to project managers and company executives. This tool is easily configurable, with several visualisation metaphors, and is able to structure data at different hierarchical levels. To obtain an initial insight into the suitability of the tool in an industrial context, an application example based on real cases and two surveys were conducted in the context of the ORIGIN industrial project. The survey aimed to evaluate the usefulness and appropriateness of the tool and was answered by a group of project and quality managers working at the INDRA Company. This is a very representative context, given that GSD is currently fundamental in the company's business.

One conclusion drawn from this study is that most of the subjects considered that the tool was useful and they affirmed that they were willing to incorporate it into their daily work. Those who responded to the first survey expressed the opinion that the possibility of customising the tool to user needs was a positive characteristic, as was that of being able to organise the data in levels. Another plus point was the use of different metaphors to visualise data. The subjects also agreed with most of the metaphors chosen for the display of the data, although most of them found the sphere metaphor difficult to understand and not so useful. The second survey confirmed that, from the software managers' perspective, the use of metaphors with different levels of visualisation is useful. The respondents to this survey considered that the specific metaphors chosen for inclusion in the tool are useful as regards making the interpretation of data easier. With regard to the possibility of customising the tool, these software managers considered that it is a necessary option. Finally, the most important point was that they believed that the tool could help them make better decisions in a GSD project.

We believe that the results obtained are encouraging and have provided interesting feedback for the future work. Our future work will be particularly focused on refining the sphere metaphor and on carrying out further empirical studies in which the tool will be applied in real environments. We also plan to develop new visualisation metaphors that will suit managers' needs, and we wish to integrate the visualisation environment into INDRA's technological infrastructure to support its managers' and executives' decision-making processes. New studies in other contexts will also be planned to reinforce the external validity of the visualisation environment.

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10 Appendix

10.1 Appendix 1

See Fig. 8

10.2 Appendix 2

See Fig. 9

Sex:	Number of Years of experience in project quality measurement
Age:	Number of Years of experience in GSD project quality measurement
Departament:	

Please assess the following statements, giving a value of 1 to 5:

1 – Totally disagree
2 – Disagree
3 – Neither agree nor disagree
4 – Agree
5 – Totally agree

A. General	Assessment Value	Observations
1. A graphical visualisation is more useful than a textual one.	1 2 3 4 5 ☐ ☐ ☐ ☐ ☐	
2. The visualisation offered by the tool (metaphors) makes the interpretation of the indicators easier than with the use of traditional graphs (e.g. Bar charts, line graphs, pie charts, etc.).	1 2 3 4 5 ☐ ☐ ☐ ☐ ☐	
B. GSD Visualisation	**Assessment Value**	**Observations**
3. The visualisation offered by the tool (metaphors) makes the interpretation of the indicators in Global Software Development easier than with the use of traditional graphs (e.g. Bar charts, line graphs, pie charts, etc.).	1 2 3 4 5 ☐ ☐ ☐ ☐ ☐	
4. Different levels are needed in an appropriate visualisation of GSD indicators	1 2 3 4 5 ☐ ☐ ☐ ☐ ☐	
5. The use of different metaphors is more appropriate in a visualisation of GSD, depending on the type of information to be displayed.	1 2 3 4 5 ☐ ☐ ☐ ☐ ☐	
C. Visualisation Metaphors	**Assessment Value**	**Observations**
6. Navigating around the scene aids interpretation.	1 2 3 4 5 ☐ ☐ ☐ ☐ ☐	
7. The possibility of going to another level by choosing an element in the metaphor aids interpretation.	1 2 3 4 5 ☐ ☐ ☐ ☐ ☐	
8. The factory metaphor is appropriate.	1 2 3 4 5 ☐ ☐ ☐ ☐ ☐	
9. The sphere metaphor is appropriate.	1 2 3 4 5 ☐ ☐ ☐ ☐ ☐	
10. The city metaphor is appropriate.	1 2 3 4 5 ☐ ☐ ☐ ☐ ☐	
D. Factory Metaphor	**Assessment Value**	**Observations**
11. It is natural - i.e., it is similar to the real-world	1 2 3 4 5 ☐ ☐ ☐ ☐ ☐	
12. It is understandable - i.e., it is easy to understand and interpret the information.	1 2 3 4 5 ☐ ☐ ☐ ☐ ☐	

Fig. 8 *DESGLOSA survey*

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13. There is enough information.	1 2 3 4 5 □ □ □ □ □	
14. It lets me draw conclusions easily.	1 2 3 4 5 □ □ □ □ □	
15. The default colors in the scene are appropriate.	1 2 3 4 5 □ □ □ □ □	
16. Navigation around the scene is important to avoid mistakes in interpretation (owing to perspective, overlapping, scaling, etc.).	1 2 3 4 5 □ □ □ □ □	
E. Sphere Metaphor	Assessment Value	Observations
17. It is natural - i.e., it is similar to the real-world.	1 2 3 4 5 □ □ □ □ □	
18. It is understandable - i.e., it is easy to understand and interpret the information.	1 2 3 4 5 □ □ □ □ □	
19. There is enough information.	1 2 3 4 5 □ □ □ □ □	
20. It lets me draw conclusions easily.	1 2 3 4 5 □ □ □ □ □	
21. The default colors in the scene are appropriate.	1 2 3 4 5 □ □ □ □ □	
22. Navigation around the scene is important to avoid mistakes in interpretation (owing to perspective, overlapping, scaling, etc.).	1 2 3 4 5 □ □ □ □ □	
F. City Metaphor	Assessment Value	Observations
23. It is natural - i.e., it is similar to the real-world.	1 2 3 4 5 □ □ □ □ □	
24. It is understandable - i.e., it is easy to understand and interpret the information.	1 2 3 4 5 □ □ □ □ □	
25. There is enough information.	1 2 3 4 5 □ □ □ □ □	
26. It lets me draw conclusions easily.	1 2 3 4 5 □ □ □ □ □	
27. The default colors in the scene are appropriate.	1 2 3 4 5 □ □ □ □ □	
28. Navigation around the scene is important to avoid mistakes in interpretation (owing to perspective, overlapping, scaling, etc.).	1 2 3 4 5 □ □ □ □ □	
G. The Tool	Assessment Value	Observations
29. It is important to be able to configure which graphic element of a metaphor corresponds with a particular indicator.	1 2 3 4 5 □ □ □ □ □	
30. It is important for the user to be able to configure the visualization measures and the metaphor to be used in each one.	1 2 3 4 5 □ □ □ □ □	
31. The tool is easy to use.	1 2 3 4 5 □ □ □ □ □	

Fig. 8 *Continued*

Number of Years of experience in project quality measurement	
Indicators normally used in software development ☐ Quality ☐ Project Estimation ☐ Requirements ☐ Testing ☐ Productivity ☐ Others	

Please assess the following statements, giving a value of 1 to 5:

1 - Totally disagree
2 - Disagree
3 - Neither agree nor disagree
4 - Agree
5 - Totally agree

Questions	Assessment Value
1. The visualisation offered by the tool (metaphors) makes the interpretation of the indicators easier than with the use of traditional graphs (e.g. Bar charts, line graphs, pie charts, etc.).	1 2 3 4 5 ☐ ☐ ☐ ☐ ☐
2. It is appropriate to have different means of visualisation (metaphors) for different data types	1 2 3 4 5 ☐ ☐ ☐ ☐ ☐
3. Navigating or moving around the scene helps in data interpretation.	1 2 3 4 5 ☐ ☐ ☐ ☐ ☐
4. Having different levels of visualisation along with the possibility of navigating among levels facilitates the interpretation.	1 2 3 4 5 ☐ ☐ ☐ ☐ ☐
5. The factory metaphor is useful as regards making data interpretation easier.	1 2 3 4 5 ☐ ☐ ☐ ☐ ☐
6. The sphere metaphor (projects) as regards making data interpretation easier.	1 2 3 4 5 ☐ ☐ ☐ ☐ ☐
7. The city metaphor (towers) is useful as regards making data interpretation easier.	1 2 3 4 5 ☐ ☐ ☐ ☐ ☐
8. It is important to be able to map an indicator with a graphic element in the metaphor (e.g. tower height with lines of code)	1 2 3 4 5 ☐ ☐ ☐ ☐ ☐
9. It is important to be able to choose the visualization metaphor for each level (global, factories of a company, projects and sub-projects)	1 2 3 4 5 ☐ ☐ ☐ ☐ ☐
10. The tool could help me to make better decisions in a GSD Project	1 2 3 4 5 ☐ ☐ ☐ ☐ ☐
Please write down any observations, improvements or suggestions that you have about the tool.	

Fig. 9 *DESGLOSA survey II*

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