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E-mail: ijsi@iscas.ac.cn
http://www.ijsi.org
Tel: +86-10-62661040

3DRC Visualizations to Support the Reconciliation of Diverging Project Views

Rossella Aiello, Gennaro Costagliola, Giancarlo Nota, and Fabrizio Torre

(University of Salerno, Italy)

Abstract In recent years there has been a growth in size and complexity of the projects managed by public or private organizations. This leads to increased probability of project failures, frequently due to the difficulty and the ability to achieve the objectives such as on-time delivery, cost containment, expected quality achievement. In particular, one of the most common causes of project failure is the very high degree of uncertainty that affects the expected performance of the project, especially when different stakeholders with divergent aims and goals are involved in the project.

To address the prevention and proactive handling of the potential controversies among project stakeholders we propose the 3DRC visualization technique and its prototypical implementation. The approach is based on 3D radar charts to allow easier and more immediate analysis and management of the project views giving a contribution in reducing the project uncertainty and, consequently, the risk of project failure. In order to explore its potentiality, the approach has been implemented by developing the 3DRC Tool, applied to a real case and validated with promising results through a user study.
Key words: 3D radar charts; project management; controversy resolution; information visualization; spatial-temporal data; multi-dimensional data; visual analytics

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1 Introduction

Nowadays the management of projects for public or private organizations is becoming increasingly difficult due to their growth in size and complexity. Statistical analysis[5,20] highlights how projects fail at an alarming rate because of the difficulty and the ability to achieve the objectives. Among the most frequent causes there is the very high degree of *uncertainty* that affects the expected performance of the project. If the projects become more complex for a number of reasons ranging from the size of the technical complexity, or environmental conflicts or political constraints, then the usual project management methodologies need to be adapted as well as managers must be able to analyze situations from different perspectives and work using a larger number of models. The lack of involvement in the project of the various stakeholders also contributes to increase the uncertainty[14,25,38] about their satisfaction degree, especially when the points of view of involved stakeholders are not consistent.

Corresponding author: Gennaro Costagliola, Email: gencos@unisa.it
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Providing new tools for visualization and analysis would be of great help to reduce project failures. In this context, an aid may come from the use of Information visualization (IV), whose usefulness has been demonstrated in many areas[9,10,11,12]. Graphical representations such as Gantt graphs, network diagrams, S-curve histograms or those considered by Earned Value Analysis[1,4] to measure project performance in areas such as cost, schedule and scope are very frequently applied in Project Management. While these techniques are basically bi-dimensional, our assumption is that 3D-based layouts of project variables and management techniques may increase the analysis capability of project managers and other stakeholders.

A 3D-based model[2] and an implementation for it have been introduced in this paper to represent and analyze the problem of diverging stakeholders views during a project execution; this 3D representation supports the project managers and stakeholders in highlighting the points of divergence or convergence between two or more stakeholders and in comparing multiple trends over time. To support experiments towards these goals and to display the 3DRC features, the 3DRC Tool was developed. Moreover, a user study was run in order to validate the model.

The paper is structured as follows: Section 2 summarizes the existing techniques in literature for creating three-dimensional Kiviat diagrams while Section 3 exploits the concept of "consonance" as a reducing factor of the project risks together with some basic definitions about the concept of stakeholders views and gap. The 3DRC model is presented in Section 4 while Section 5 describes a tool implementing the 3DRC approach. Section 6 presents the model validation and, finally, the last Section contains the conclusions and discusses future work.

2 Related Work

In this Section, we give some motivations on the use of 3D over 2D visualizations and present some 3D successful approaches based on the extension of radar charts. In many cases, 3D visualizations also include 2D elements such as landscape, text and tables. In these cases the terminology 2.5D is sometimes used in literature[36]. In this paper, for simplicity, we only use the term 3D to refer to representations which are not 2D.

2.1 2D vs 3D representations

The real world is three-dimensional and it becomes "four-dimensional" when the time is included. Since there are obvious advantages in the use of traditional techniques (2D), some considerations are required[37]:

- the science of cognition indicates that the most powerful pattern-finding mechanisms of the brain work in 2D and not 3D;
- there is already a robust and effective methodology about the design of diagrams and the data representation in two dimensions;
- 2D diagrams can be easily included in books and reports;
- it is easy to come across an abundance of ill-conceived 3D design.

In light of the above considerations, why it is worth to study 3D-based approaches?

A 3D representation has several advantages[7,24,30,34,35]:

- *Shape constancy*: it is the property that allows us to recognize from several points of view, irrespective of the particular 2D image projected onto the retina, the 3D shape of an object (or part of it);
- *Shape Perception*: unfamiliar shapes stand out immediately. This is done "unconsciously" and requires minimal cognitive effort;
- The use of 3D shapes enable us to encode more information than other visual properties such as scale, weight, and color;
- Users can take advantage of 3D displays to visualize large sets of hierarchical data;
- It is possible to show more objects in a single screen thanks to the perspective nature of 3D representations;
- If information is visible at the same time, users gain a global view of the data structure;

A quite convincing reason for an interest in 3D space perception and hence searching for new methodologies for the 3D data representation is the explosive growth of studies on 3D computer graphics. Today there are several software libraries that allow programmers to rapidly develop interactive three-dimensional virtual spaces. Last but not least, 3D printing is now becoming more and more accessible. Unfortunately there are also disadvantages that must be taken into account when designing 3D visual interfaces:

- The problem of occlusion: in a 3D scene, foreground objects necessarily block the view of the background objects.
- A lower data/pixel ratio than 2D visualizations: this significantly limits the quantity of visible data.

Since "in medio stat virtus" the best choice is to employ both the approaches. It is likely that a system allowing the user to easily switch from a 2D to a 3D display, and vice versa, would be beneficial for the user. In fact, this would enable us to extend the plethora of tools at our disposal for understanding data sets.
In developing the 3DRC model a thorough study has been made on the different techniques both to maximize the benefits and reduce the problems regarding the usage of a 3D representation with a definition of a not ambiguous visual representation of the semantics.

2.2 Radar charts

A radar chart (also known as Kiviat diagram) is a two-dimensional graphical representation of multivariate data with one spoke for each variable. The sequence of spokes, or radii, is equi-angular and starts from the same central point which represents zero. The angle of the axes and relative position is typically uninformative. A radar chart requires at least three categories; the length of each spoke is proportional to the size of the variable relative to the maximum size of the variable across all data points. The data values for each spoke are connected by a line giving the plot a star-like appearance. Each star represents a single observation. A radar chart represents multiple observations through multi-plot format with many stars on each page and each star representing one observation.

This plot is useful to answer to the following questions:

- Which observations are most similar?
- What variables are dominant for a given observation?
- Are there outliers?
- Can entities and relationships with critical trends be easily identified?

Radar charts are a well established visualization tool and are used in many contexts such as large volumes of information[15,18,29] or for presenting multivariate health care data[32], or other.

In addition, they allow to accommodate additional information without becoming overwhelming, by simply adding spokes to the wheel, and result less cluttered compared to other techniques for the visualization of multidimensional data (e.g., Bar graph, X-Y plots).

These advantages are still valid when radar charts are disposed along the time axis to produce a 3D radar chart.

As a matter of fact, several researches on 3D radar-chart construction can be found in literature. Among the most interesting we cite Guo and Kerren[21,23] who proposed a 3D Kiviat diagram in which the same axes are folded up and down in 3D (Fig. 1), with the result of allowing the observer to better perceive the data-dependent time.

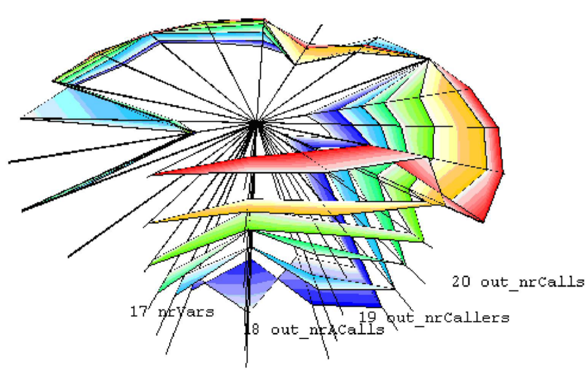


Figure 1. A 3D radar-chart according to Guo (image taken from Ref. [21]).

The Kiviat tubes, as suggested by Hackstadt and Malony in Ref. [22], are achieved by rendering the surrounding surface obtained by displaying Kiviat diagrams placed along a time axis. In the first version the surface connecting all the Kiviat diagrams emphasizes the shape of the tube but hides the information about individual data elements. This inconvenience has been solved thanks to transparencies and composition techniques that allow an improved display which lets scroll a slice of a 2D Kiviat diagram through a partially transparent Kiviat tube.

Fanea et al.[16] extended the 2D Parallel coordinates in 3D Parallel coordinates, by combining multiple views of 2D parallel coordinates in a single view. This was achieved by placing the matrix diagrams of 2D Kiviat in a cylinder aligned along the time axis and connecting the vertices with polylines. The result of this approach is similar to 3D Kiviat tubes; unfortunately, the amount of data sets that can be displayed is still limited because when too much data must be handled, their recognition and comparison can be very difficult.

Tominski et al.[33] presented some approaches to achieve an interactive visualization based on the axes that can be used to explore and analyze multivariate time series data. The main idea is to arrange the axes to form a circle around a commonly shared time axis and render, for each time step, a surface representing a Kiviat diagram, see Fig. 2.

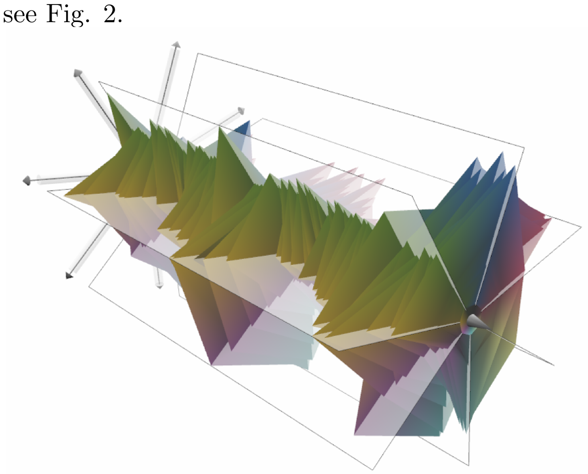


Figure 2. A 3D Kiviat tube displays seven attributes respect to the central axis of time (image taken from Ref. [33]).

The Wakame[17] are obtained with a very similar approach to those used by Hackstadt and Malony or Tominski et al. for the construction of their Kiviat tubes. A traditional multi-dimensional radar chart is drawn on the bottom using a 3D representation. As with other extrusion techniques, the time is mapped along the y axis, and the various sequential measures become radar-chart drawn at different heights above the floor from the bottom upwards. These drawings are used to create "hollow tubes" whose shape illustrates the changes in data over time. Compared to the original implementation where each Wakame is colored with a unique color, the new prototype assigns a different color to each of the vertices that correspond to the different sizes. With this coloration, both the overall shape and shape changes inside each dimension are more easily comprehensible.

Furthermore, a Wakame also allows the comparison of an heterogeneous data collection emphasizing the possible correlations.

3 Using Consonance to Increase Project Agreements

According to the Viable System Approach[3,19], *consonance* is considered as a potential compatibility between systems, that facilitates their connection. The virtuous interaction (harmonizing) between two active entities becomes the *resonance*. While consonance concerns structural concepts, resonance is a systemic concept. The consonance represents a situation aiming at reaching an harmony or agreement among two or more systems, but they effectively become resonant when an harmonic interaction between components exists. In Ref. [26] the authors discuss how an agreement on a contractual basis for a project realization creates a situation of consonance among the contractors that appears to be the minimum necessary to enable the resonance. The stakeholders will to contract indicates that exists a relationship of trust and harmony that comes from sharing the same design goals. When strategy, mutual commitments, values and goals are shared, a cooperative behavior emerges from the system composed of the stakeholders. If some conflict of interest arises, each stakeholder (and, in general, each system) must identify the best possible way to cooperate, possibly changing its behavior to reach the convergence of individual perspectives. However, it is not always possible to predict in advance and manage the risks of adverse events to the project realization; in addition, due to the conflicting and opportunistic roles that stakeholders hold, positions and different views on one or more project activities often emerge. In these cases, the balance achieved in the degree of initial consonance is disturbed and some corrective actions need to be provided by one or both parties, to try to restore it to the initial levels or at the levels considered as satisfactory for the project continuation. Some negotiation cycles are necessary before reaching an agreement on potential controversies generated during the project. A feedback model formalizing this situation, is discussed in Refs. [26,28] where contract management together with dispute management act as a regulatory instruments to maintain adequate levels of consonance and resonance among systems cooperating for the achievement of a common goal. In the following we provide some definitions[27,28], on which the 3DRC visualization technique is based.

In the paper, we explain our approach considering as a case study "COSMO Project - Contract & SLA Management Outlook" financed by Campania Region (in the South of Italy) with POR 2000-2006 - Measure 3.17. The project had a duration of 18 months from September 2008 and it was presented by a Virtual Enterprise composed of four companies of Campania Region, together with the University of Benevento (Department of Engineering). COSMO project was divided in nine work packages with a total of 39 activities. Each activity was assigned to a partner ($P_i, i = 1, \ldots, 4$) with the coordination of the leading company (LC) that had also the role of the front-end towards the administration offices of Campania Region. Three official project milestones were provided for the reporting of the project, but also other internal milestones were established among the partners to control the execution and the exchange of information and project documentation.

3.1 Definition of project

A project can be seen as a set of sequential and/or parallel activities. We define a project P as a set of quadruple:

$$P = \{[a_1, c_1, s_1, q_1], [a_2, c_2, s_2, q_2], \cdots, [a_m, c_m, s_m, q_m]\} \tag{1}$$

where $a_1, \cdots, a_m$ are the project activities and:

- $c_1, \cdots, c_m$ are the associated planned costs,
- $s_1, \cdots, s_m$ are the scheduled execution times where each $s_i = [t_{start}, t_{end}, state]$ $i = 1, \ldots, m$ with the attribute *state* that, at a given time, can assume one of the values contained in the collection {`started`, `not started`, `in progress`, `suspended`, `completed`}.
- $q_1, \cdots, q_m$ define the quality constraints specified in relation to the output design.

3.2 Definition of view

We now introduce the concept of view associated with each contractor at a certain time instant. Assume that two contractors A and B have signed a contract at time t_0. At a generic time $t > t_0$ each contractor $x \in \{A, B\}$ has the following point of view with respect to the execution of the project P:

$$View_x(P, t) = \left\{[a_i, c_i^t, s_i^t, q_i^t]\right\} i = 1, \ldots, m$$

where:

- each c_i^t represents the cost assigned by x at time t with respect to the activity a_i
- each $s_i^t = [t_{start}, t, state]$ is the time observed for implementing the activity a_i until t
- each q_i^t indicates the degree of quality observed by x on activity a_i at the observation time.

At time $t_0, View_A = View_B$ because the parties have reached a contractual agreement; therefore, a view represents the "*planned values*" for project variables specified at time t_0. Over time, a view assumes the meaning of "*observed value*" derived from the perception that a contractor has with respect to the execution of the project activities. Since the point of view is a subjective value, it happens frequently that the views of the parts tend to vary over time. The idea of divergence on the values of fundamental project variables is formalized below by the function Δ.

Definition of gap

Supposing that two observers A and B observe an activity a_i at a generic time instant t, the *gap* between the two views is represented by the Δ_i function as follows:

$$\Delta_i(View_A, View_B, t) = [a_i, \Delta_i^c, \Delta_i^s, \Delta_i^q] \tag{2}$$

where $\Delta_i^c, \Delta_i^s, \Delta_i^q$ are the projections of the distance between the views $View_A, View_B$ on the dimensions of cost, time and quality of the activity a_i, respectively.

If the observers are interested in a subset of activities $X = \{a_1, a_2, \ldots, a_l\}, l <= m$

$$\Delta_X(View_A, View_B, t) = \{[a_j, \Delta_j^c, \Delta_j^s, \Delta_j^q]\}\ j = 1, \ldots, l \tag{3}$$

if $l = m$, A and B observe the whole project.

Focusing only on the cost dimension, the gap measured from the views of A and B for an activity a_i taken at a generic time t is:

$$\Delta_i^c = |c_i^B - c_i^A| \tag{4}$$

while, Δ^{dur} corresponds to the difference of the activity durations declared by each stakeholder[26], where duration dur at time t of an activity a_i is computed according to the following statement:

$$dur_i^t = \begin{cases} t_{end} - t_{start} & \text{if state=completed} \\ t - t_{start} & \text{if state = started} \\ undefined & \text{if state = not\_started} \end{cases} \tag{5}$$

Other details about cost and time dimension can be found in Refs. [26,27]; in subsection 3.4 we provide some detail about the evaluation of the projection Δ_i^q.

The *total gap* between two views of the subset X according a dimension d (time, cost or quality) is calculated as the sum of the gap on all activities belonging to X:

$$T\Delta_X^d(t) = \sum_{j=1}^{l} \Delta_j^d. \tag{6}$$

As above, if X contains all the activities of the project P, $T\Delta$ represents the total gap of P.

The analysis of the $T\Delta_d$ over time also gives us an idea of how the project consonance level between A and B evolves with respect to the considered dimension. If the views diverge at the time of the observation, the consonance between contractors tends to decrease. When the points of view are irreconcilable, a dispute arises slowing down or possibly stopping the project. It may then be necessary to embark on a series of informal negotiations between the contractors to re-establish an acceptable level of consonance or, in the case of irreconcilable disagreement between the parties, the initiation of a formal process of dispute resolution governed by a mediator.

3.4 The function Δ^q

According to Ref. [31] the modern quality management approaches seek to minimize variation and to deliver results that meet defined requirement in order to reach a high level of customer satisfaction, decrease costs, increase productivity and profitability.

Plan Quality Management consists in the process of identifying quality requirements and/or standards for the project and its deliverables, together with the documentation of how the project will demonstrate compliance with relevant quality requirements. In our project model, a quality requirement q_i is specified as a set of statements $\{q_{s1}^i, \ldots, q_{sn}^i\}$ expressing the needs that have to be satisfied by a product or a service at activity completion, as an example the physic characteristics of goods or services to be supplied, the realization modalities, the delivery mode and so on.

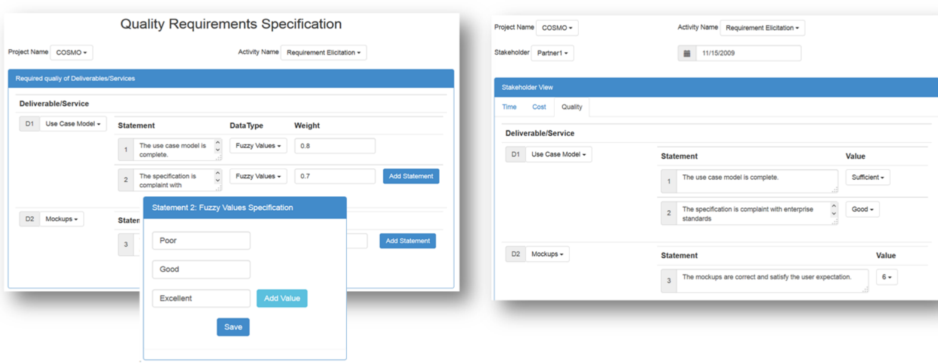
Quality measures and techniques are specific to the type of deliverables being produced by the project. Generally, each requirement q_i can be evaluated against a list of values $V(q_i)$ deriving from the analysis and evaluation of a certain predefined number of quality statements defined in the contract.

After proof, document analysis, inspection or testing a stakeholder expresses its own evaluation for a quality requirement, assigning a value v_k^i, $k = 1, \dots, n$ to each statement q_{sk}^i of q_i, in the following way:

$$V(q_i) : \{V_{s1}^i, \dots, V_{sn}^i\} \rightarrow \{v_1^i, \dots, v_n^i\}, \text{ with } v_1^i \in V_{s1}^i, \dots, v_n^i \in V_{sn}^i.$$

As an example, V_{sk}^i, with $k = 1, \dots, 3$ could be: V_{s1}^i = [`complaint/not complaint`], V_{s2}^i = [`poor, sufficient, good, very good`] and $V_{s3}^i = [0, \dots, 10]$.

Moreover, in the planning phase, a weight $\alpha \in \{0, 1\}$ is defined for each quality statement to associate the right degree of importance for every statement; in fact, even if all the statements must be verified by contract, they may have more or less importance for the purposes of an assessment of quality. For example, to a mission critical requirement, specifically requested by the client, is usually assigned a very high weight.



(a) (b)

Figure 3. (a) Quality requirements specification. (b) Quality evaluation form.

Figure 3(a) shows the quality requirements specification for the activity named *Requirement Elicitation* of the project COSMO. For it, three quality statements for the produced deliverables are specified in terms of fuzzy values. The first two concern the deliverable "Use Case Model" and the third the deliverable "Mockups". In the case of a *fuzzy values* datatype, the project manager must also insert all the values that could be associated to the datatype in the evaluation phase; as an example, for the quality statement 2, the fuzzy values are `[poor, good, excellent]`. During the evaluation phase, a stakeholder will be able to select only one value from this set, as shown in Fig. 3(b).

With the aim of quantifying the difference between quality views, a numerical representation of results must be associated to a statement: supposing that the domain V_{sk}^i contains j fuzzy values ($j > 0$), function f maps v_k^i in this way: $f(v_k^i) = l_k^i/(j-1)$ where $l_k^i \in [0, \dots, j-1]$ represents the position of v_k^i in the range.

Starting from these assumptions, the quality q_i of an activity a_i can be computed as the weighted average:

$$q_i = \frac{\sum_{k=1}^{n} \alpha_j f(v_{sk})}{n} \tag{7}$$

so, the gap Δ_i^q at time t is obtained as:

$$\Delta_i^q = |q_i^A - q_i^B| \tag{8}$$

Table 1 Data summary about activity a_1

Observation Time	Attribute	Planned	$\mathbf{View}_{P_2}(A_1)$	$\mathbf{View}_{LC}(A_1)$	$\mathbf{View}_{CR}(A_1)$
	Start	1 Oct 2008	15 Oct 2008	15 Oct 2008	15 Oct 2008
	End	3 Nov 2008	24 Nov 2008	2 Dec 2008	4 Dec 2008
t_1:6 nov 2008	**State**	completed	in progress	in progress	
	Time	$\Delta_i^{dur}(Planned, P_2) = 12$	$\Delta_i^{dur}(P_2, LC)$=0		
	Cost	12390	10725	9780	
		$\Delta_i^c(Planned, P_2)$=1665	$\Delta_i^c(P_2, LC)$=945		
	Quality	D1.1:4	D1.1:4	D1.1:3	
		$\Delta_i^q(Planned, P_2) = 0$	$\Delta_i^q(P_2, LC)$=1		
t_2:27 nov 2008	**State**	completed	completed	in progress	
	Time	$\Delta_i^{dur}(Planned, P2)$=6	$\Delta_i^{dur}(P_2, LC)$=3		
	Cost	12390	12390	11890	
		$\Delta_i^c(Planned, P_2)$=0	$\Delta_i^c(P_2, LC)$=500		
	Quality	D1.2:4	D1.1: 4,D1.2: 4	D1.1:4, D1.2:2	
		$\Delta_i^q(Planned, P_2) = 0$	$\Delta_i^q(P_2, LC)$=2		
t_3:2 dec 2008	**State**	completed	completed	completed	
	Time	$\Delta_i^{dur}(Planned, P_2)$=6	$\Delta_i^{dur}(P_2, LC)$=8		
	Cost	12390	12390	12035	
		$\Delta_i^c(Planned, P_2)$=0	$\Delta_i^c(P_2, LC)$=355		
	Quality	D1:4	D1:4	D1:4	
		$\Delta_i^q(Planned, P_2) = 0$	$\Delta_i^q(P_2, LC)$=0		
t_4:15 feb 2009	**Cost**	12390	12390		11650
					$\Delta_i^c(P_2, CR)$=740

In the rest of the section, we apply the case study that exemplifies the use of the definitions. Table 1 summarizes data about the activity a_1 of the COSMO project. This activity was assigned to the partner P_2 and three internal milestones were defined by LC for the monitoring. The *Planned* column shows activity data as approved by Campania Region to be eligible for funding. Other two columns on the right compare P_2 and LC views respectively while the last column visualizes the official cost data recognized by Campania Region after the first Project Review Meeting.

Δ^c is obtained as the difference between declared costs while the quality dimension has been summarized with a range of numbers between 0 and 4, where each number in the range indicates the corresponding value in the set {`not complaint, low quality, sufficient quality (or complaint), good quality, excellent`}.

By data comparison at the first milestone, different perceptions about activity state can be observed. With respect to the planned values, P_2 declares the beginning of activity as shifted of 15 days, and duration shows a gap of about 6 days while gaps on cost and quality arise because the activity is still running. Comparing the views of P_2 and LC, we observe that LC confirms the shifting of the activity start and some differences with respect to the planned values also remain in duration (time t_1); moreover, there are gaps on other two dimensions, due to the missing of some statements of expenditure and a delay in the delivery of the preliminary version of project document D1. At the second milestone t_2, after an exchange of other documents, the gap about the cost decreases while there is a greater quality gap on the second section of D1: for LC the activity is still running while P_2 declares its completion. An agreement is reached at t_3 when the activity results completed and the deliverable is accepted by LC. Finally, according to the official milestone, financial reporting made by Campania Region (RC) shows a difference in the cost because some expenditures resulted as not eligible.

The visualization and the comprehension of COSMO tabular data become more difficult as number of activities, stakeholders and milestone increases; Table 1 shows only gaps about one of the total activities of the project and, even if it is very simple, its analysis is not immediate. In the following we introduce a graphical approach for the representation of gaps with the aim to give an immediate perception of the trend of an activity or a project, according to the stakeholders point of view.

4 The 3DRC Model

In this research, a 3D graphical visualization technique based on radar charts has been applied to the specific problem of the representation and analysis of divergent views and their variations in time, according to the definitions presented in the previous section. For each gap $\Delta_i(View_A, View_B, t_k)$ between the views of two observers A and B at time t_k for activity i we define the *radar chart* $rc_i^{t_k}(A, B)$ as shown in Fig. 4(a), where the three axes represent the three components $\Delta_i^c, \Delta_i^s, \Delta_i^q$. These components are then normalized.

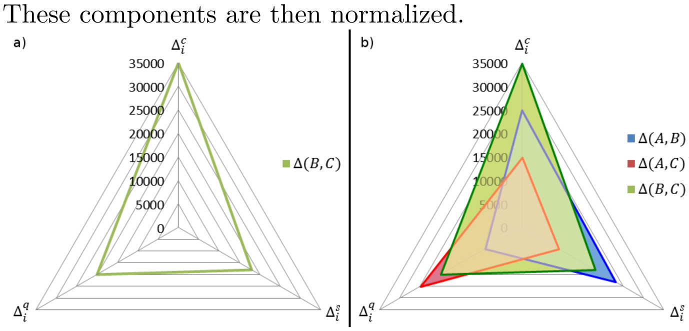


Figure 4. Radar chart representations of gaps between stakeholders A and B (a) and stakeholders A, B, C (b).

Here, the radar chart approach gives two important contributions:

- it provides a simplified presentation of the gaps between stakeholders, making them visible even to non-experts;

- the figure formed by the three (or more) axes of the radar chart not only provides a visual representation of gap between stakeholders, but its surface area also gives a composite indicator of the Δ_i function, as opposed to the separate projections $\Delta_i^c, \Delta_i^s, \Delta_i^q$.

Therefore, a radar chart allows us to easily detect the following information:

– the variations of a single component Δ_i^d with respect to another;

– a relative measure of the size of the gap Δ_i: the smaller the triangle area (with the vertices that tend to the center axis), the smaller Δ_i.

The *composite radar chart* $rc_i^{t_k}(A, B, C)$ shown in Fig. 4(b) is obtained from the three radar charts $rc_i^{t_k}(A, B)$, $rc_i^{t_k}(A, C)$, $rc_i^{t_k}(B, C)$ in the following way:

$$rc_i^{t_k}(A, B, C) = rc_i^{t_k}(A, B) \uplus rc_i^{t_k}(A, C) \uplus rc_i^{t_k}(B, C) \tag{9}$$

where the operator $\uplus$ indicates the overlap operation on radar charts. Composite radar charts allow to effectively compare Δ_i to highlight the points of divergence or convergence between more than two stakeholders by giving an immediate identification of the differences among gaps.

To display the variation of one Δ_i with respect to time, a *3-Dimensional Radar Chart (3DRC)* is introduced as a temporal sequence of radar charts:

$$3DRC_i^{A,B} = \langle rc_i^{t_0}, rc_i^{t_1}, \ldots, rc_i^{t_k} \rangle \tag{10}$$

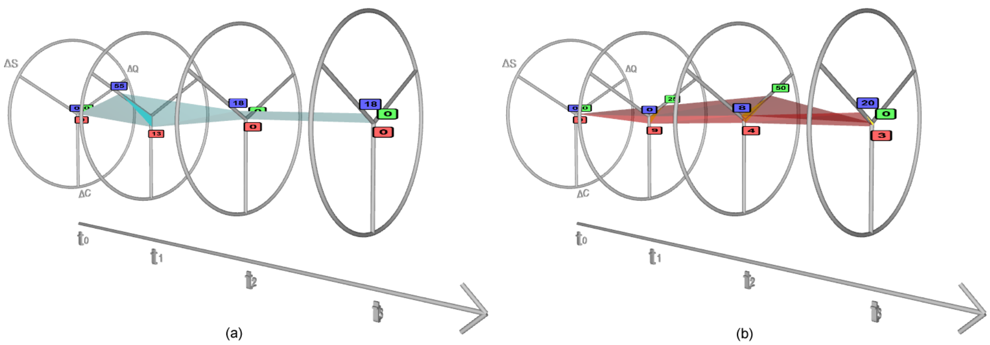


Figure 5. The 3DRC generated about diverging views between stakeholders: Planned and P_2 (a) and P_2 and L_C (b).

In other words, a 3DRC represents the trend of a radar chart over time Figure 5 illustrates two 3DRCs obtained by the data contained in Table 1. The first (Fig. 5(a)) shows the gap between stakeholders P_2 with respect to the Planned values while the second (Fig. 5(b)) indicates the difference between the perception of stakeholders P_2 and L_C. By analyzing the two graphical representations, an observer immediately perceives the difference between what P_2 declares and what the controller (in this case the leading company LC) verifies. According to the P_2 view the activity a_1 has a trend very close to the planned values (Fig. 5(a)) while the control action made by the leading company highlights a lowest quality than that required. In order to compare multiple trends over time, two or more 3DRCs can be overlapped. In particular, this is useful to visualize the trends of more than two stakeholders at the same time. The composite 3DRC for stakeholders A, B, and C is obtained as follows:

$$c3DRC_i^{A,B,C} = 3DRC_i^{A,B} \uplus 3DRC_i^{A,C} \uplus 3DRC_i^{B,C} \tag{11}$$

The definition stated above for radar charts and 3DRC on activity a_i also continues to be valid for a subset $X = a_1, a_2, \ldots, a_k$ of activities. Indeed, for stakeholders A and B, the radar chart $rc_X^{t_k}(A, B)$ gives the representation of $T\Delta_X$ where the value of each component Δ_X^d $\forall d \in \{c, s, q\}$ is obtained as a sum of all the Δ_i^d $\forall i \in \{1, \ldots, k\}$ and $\forall d \in \{c, s, q\}$; we then define the resulting 3DRC as follows:

$$3DRC_X^{A,B} = \langle rc_X^{t_0}, rc_X^{t_1}, \ldots, rc_X^{t_k} \rangle \tag{12}$$

If X contains all the project activities, the radar charts correspond to the representation of the total gap $T\Delta$. Figure. 6(a) illustrates two 3DRCs respectively concerning the view of P_3 and LC about the workpackage W3 of COSMO project before the second official Project Review Meeting while Fig. 6(b) represents their overlap. W3 contained eight activities from a_5 through a_{13} related to the implementation of the three main COSMO subsystems. As highlighted by the figure, the perception of P_3 about its work on W3 tends to converge towards a smaller gap over time; on the contrary, the LC view diverges and highlights an increment of gap for the workpackage due to the wider knowledge that the leading company must also have about the partners work. In this specific case, the divergent gap was due to a great delay of P_1 on two very critical activities; to reduce the high risk of project failure, LC decided to switch part of the two delayed activities to another partner.

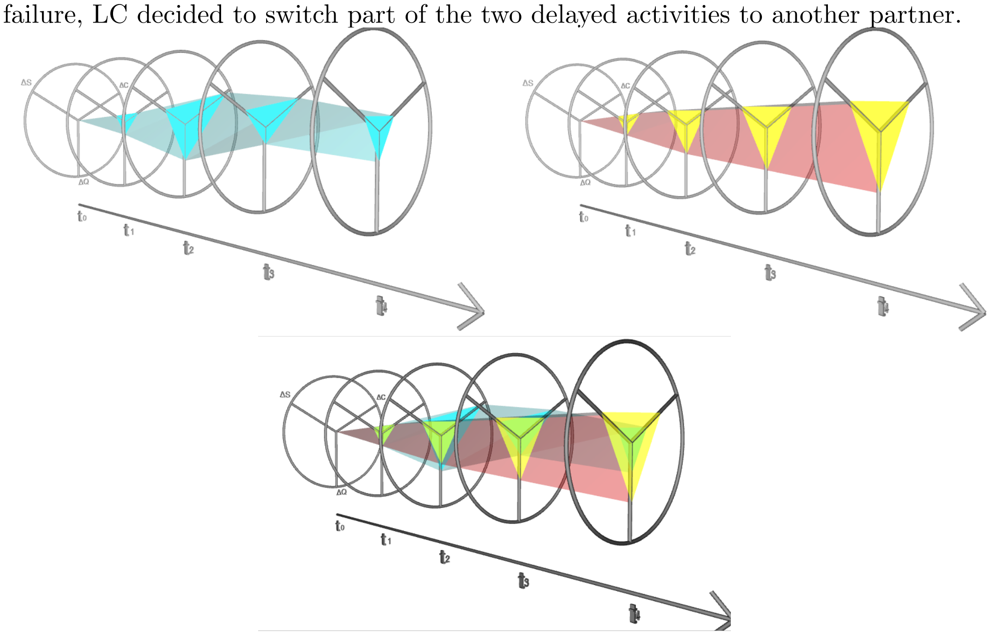


Figure 6. The overlapping of two 3DRCs.

The visualization algorithm places a circumference with three equally spaced radii representing the three components Δ_i^c, Δ_i^s, Δ_i^q at the origin of the t-axis representing the time; it draws a 3DRC$_i$ starting with a point at time t_0 (that means gap=0 at time of contract signing) and going on with radar-charts at discrete points of the *time*-axis. In other words, with an approach similar to Refs. [17,22,33], the time is mapped along the t axis, and the various sequential measures of the function Δ are represented as radar-charts drawn on the t axis. Depending on the visual needs, the time intervals are drawn either as normalised at an equal distance or respecting the real effective distances. As in Ref. [16], the model connects the vertices of the radar charts with polylines and assigns a single transparent color to the resulting solid obtaining something like a piece of transparent glass. In fact these drawings are used to create “filled tubes”.

When a composite 3DRC must be created, a different color is assigned to every single 3DRC to distinguish the different stakeholders views.

While in other implementations of Kiviat tubes the visual information is shown on the surface of the tube, in our case the information is represented in the volume variations that the 3DRC assumes along the time.

4.1 3D Shape perception: learning by observing

From the field of perceptual psychology[7,35] there is evidence that:

- the repeated viewing of a 3D shape is impressed rapidly in memory (see Sec. 2.1);
- unfamiliar shapes stand out immediately. This is done “unconsciously” and requires minimal cognitive effort (see Sec. 2.1).

Thanks to these properties the graphical appearance of a 3DRC is used to

1. observe all three components of Δ_i at a glance (such as in Fig. 4);
2. distinguish the individual radar charts composing the 3DRC to see how the views between two stakeholders about an activity (or a subset of activities) change across the time (as shown in Fig. 5);
3. overlap 3DRCs to understand how different stakeholders interact with each other across the time on the same activity (or subset of activities) (such as in Fig. 6);
4. overlap two or more 3DRCs in order to compare different activities and eventually discover some hidden correlations between them.

Figure 7 shows how a series of radar charts move in a certain direction over time to immediately understand the presence of some critical issues that could reveal some potential controversies. When the agreement and thus the consonance among stakeholders have a constant trend, Δ values show little variations with respect to the planned values while greater variations in one or more components draw attention to different points of view of stakeholders about the correct project execution. By observing a 3DRC we note that a “contraction” of diverging views indicates a reconciliation between those views observed through the increment of consonance among the stakeholders.

In order to augment the model with some alerting functions, two cylinders are added to a 3DRC: the internal cylinder defines a green zone representing an acceptable consonance situation while the external one delimits the maximum tolerance beyond which it is very hard to restore the minimum necessary consonance to continue the project (red zone). The intermediate area (yellow zone) indicates a divergence of points of view that requires some smooth actions by stakeholders to converge towards more tolerant consonance values. In the following, we define some alerting functions. Given:

- $CircumferenceArea_{\min}$: the area of circumference of radius min, where min is the minimum tolerance degree;
- $CircumferenceArea_{\max}$: the area of circumference of radius max, where max is the maximum tolerance degree;
- $Distance_{\Delta^d}$ represents the position of the radar chart vertices on the axes; it coincides with the value of Δ_i^d;

we have the following relations:

- for each radar chart in a 3DRC, if the $Distance_{\Delta^d} \leqslant \min$ for each dimension $d \in \{c, t, q\}$ (see Fig. 7 at time t_1 and t_4) then the consonance is acceptable.
- If some components of Δ_i in one or more radar charts are outside $CircumferenceArea_{\min}$ but inside $CircumferenceArea_{\max}$, in other words $\exists\ d \in \{c, t, q\} \mid Distance_{\Delta^d} > \min$ and $Distance_{\Delta^d} < \max$, then there is a partial consonance.
- If some components of the Delta function are outside the $CircumferenceArea_{\max}$ then a high risk situation for the project has highlighted.

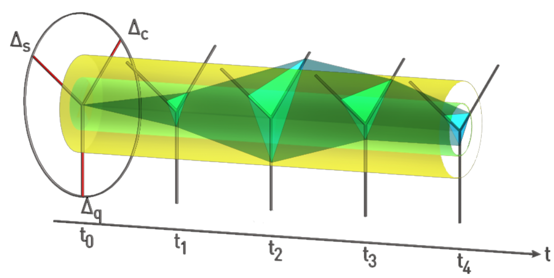


Figure 7. Example of monitoring not exceeded the minimum constraints of consonance.

The overlapping of 3DRCs can also be executed when we consider 3DRCs representing the trend of stakeholders views about different activities. If we consider 3DRC for a set of activities X, the composite 3DRC is obtained as follows:

$$3DRC_X^{A,B} = \biguplus_{j \in X} 3DRC_j^{A,B} \tag{13}$$

With this operation it is possible to analyze the possible relationships among activities and to answer questions like the following:

- May a high gap on an activity have brought benefits or disadvantages to the execution of another one?
- Could some actions aimed at reducing a gap have an impact on other activities?

As an example, if there is an activity with a cost higher than the one planned, the company will probably tend to compensate this extra cost reducing the assigned resources or the quality of some other activities. By composition and comparison of

3DRCs, the analyst has a visual and more immediate perception of the cause-effect relations among activities having also a valid support for the monitoring and the proactive control of the project execution. A great advantage of the use of 3DRC is the scalability of the project analysis: a 3DRC can be created by the selection of a set of project activies (see eq. (12)). It is possible to perform:

- a *top-down analysis*, the project manager starts from the overall project data to create a 3DRC and he/she gradually details the analysis focusing the attention on workpackages and activities (like the example described in Fig. 6);
- a *bottom-up analysis*, where critical analysis are considered before and then data are grouped to considered subsets of activities or entire workpackages.

Moreover, a project is very often composed of activities that, for their intrinsic complexity, are executed by a stakeholder by instantiating a subproject. In this case, each stakeholder can locally work on subprojects.

5 The 3DRC Tool

This section provides a description of the 3DRC Tool. In order to explore and develop the 3DRC visualization approach together with the analytical characteristics of the user interface, a prototype system capable of displaying multi-dimensional time-based data was implemented. The figures and examples used in this section have been elaborated based on the data obtained by the COSMO Project.

5.1 System architecture

The 3DRC Tool consists of four modules (see Fig. 8), each responsible of a particular task:

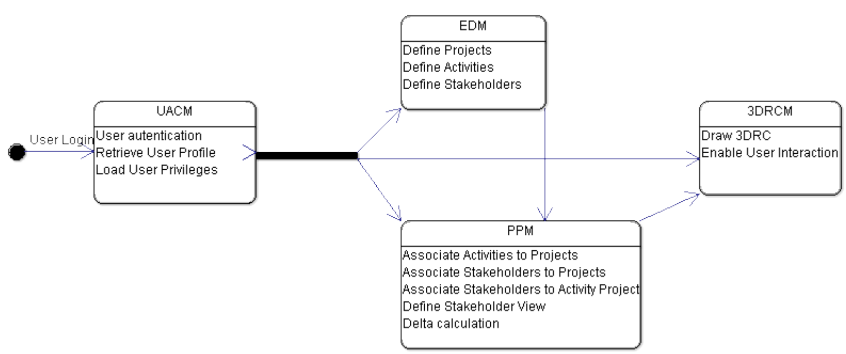


Figure 8. The 3DRC tool logic modules.

- User Access Control Module (UACM): the module for user administration. UACM performs the operation to define:
  - the users who can log into the system;

  – the criteria for the profiling of registered users and their permissions;
  – the access control.

  Moreover, this module has been designed to provide an appropriate level of security in order to prevent unauthorized access and to protect the newly discovered knowledge and the users identity.

– Entity Definition Module (EDM): the module for the project definition. This module allows us to define/modify projects, activities and stakeholders. The EDM interacts with the UACM to retrieve the set of allowed operations for each user. In addition, this module allows to export or import the project information and/or stakeholder views from/to an XML file.

– Project Population Module (PPM): the module for the population of a project. It allows to assign activities and stakeholders to individual projects. After completing the activity-stakeholder associations, the user will be able to create and populate its view on a specific activity project. This module also deals with the calculation of Δ, for each activity offering a preview of the 2D radar chart (and therefore of the three components Δ_c, Δ_q and Δ_t) which will be useful for the creation of 3DRC. This module interacts with the EDM for the retrieval of projects, activities and stakeholders defined by a user and with the UACM for the obtainment of the allowed operation set.

– 3DRC Module (3DRCM): the display module. It generates 3DRC starting from the data processed by the PPM. Any change in PPM triggers an update to the appearance of the 3DRC in the 3DRCM. This module interacts with the UACM for the retrieval of 3DRCs that a user is authorized to visualize. The 3DRCM also provides a set of operations to interact with 3DRC (see Section 5.2).

5.2 Interacting with 3DRCs

The traditional desktop interfaces are based on using the conventional WIMP desktop metaphor (Windows, Icons, Menus and Pointer) with a control panel, push buttons, and checkboxes. For touch-based devices it is also available another interface, called FLUID, that eliminates the control panel and uses touch to define actions on the visualized data. Nowadays, application developers need to consider the increasingly spread of touch-based devices (tablet, smart phone, etc.). For these reasons, when dealing with these devices, they are faced with a dilemma in implementing interactions: do we simply port the familiar WIMP-style interfaces by only replacing the mouse click with a finger tap?; or should we change the interaction style to a more "touch-centric" interface that affords more direct manipulation of that application[13]?

The early 3DRC Tool Prototype was created to run on traditional desktop systems while the current 3DRCM partially supports the use of a "touch-centric" interface.

To meet the user needs and also execute the 3DRC Tool satisfactorily on tablets, smart-phones, etc., a GUI able to switch, as much as possible, from a WIMP to a FLUID interface depending on the device has been implemented.

Figure 9 shows the interface of the prototype implementing the 3DRC visualization model. The users mainly interact with this interface through the mouse and keyboard or using the finger on a touch-screen. The main available operations are:

- *Space rotation*: the 3D space containing the 3DRCs can be rotated around one or more axes. The effect is the changing of the point of view for the visualized items. The operation is performed by clicking the left button and moving the mouse or by dragging a finger on the touch-screen;
- *Space shift*: the 3D space containing the 3DRCs can be moved along the x and y axes. The operation is performed by clicking the right button and moving the mouse or by dragging three fingers on the touch-screen;
- *T-rotation*: a single 3DRC can be rotated on its center around the t-axis (see Fig. 10). The effect is the changing of the point of view for the visualized items. This operation entails a rotation of the three Delta vectors. The operation is performed by clicking the left button on the center axis of the 3DRC and rotating the mouse wheel or by tapping with a finger on the touch-screen and use an other finger to pivot around the first; the cylinder can alternatively be animated by pressing the Play button in the toolbox associate to the 3DRC;

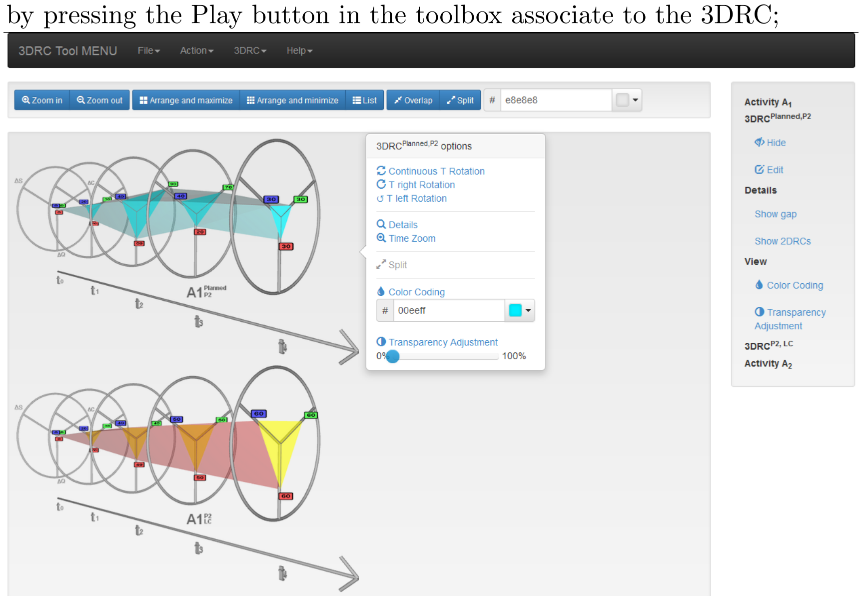


Figure 9. The interface of the prototype.

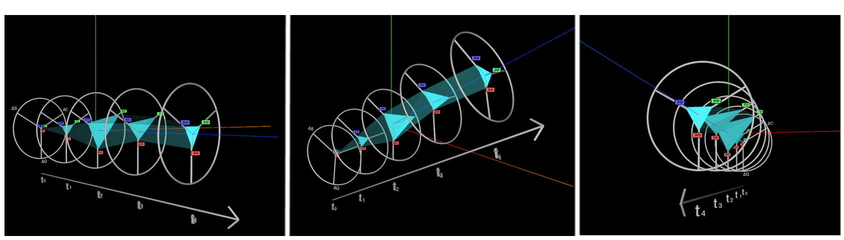


Figure 10. An example of T-rotation on 3DRC.

– *Tooltip*: when the user hovers the cursor over an item, a box containing

$$(\Delta(View_{User_i}, View_{User_j}),\ T\Delta_d(View_{User_i}, View_{User_j})$$

appears; an arrow indicates whether the trends of the gaps are increasing or decreasing with respect to a particular size;

– *Details*: further details are obtained when the user clicks over an item. The item is selected and the selection is highlighted through a yellow light surrounding the item. Details of the selected item (see Fig. 11) are shown in the *details view* and they include, as an example, the monitoring panel for the GAP analysis of project activities or the possibility of seeing the single radar chart associated with that item;

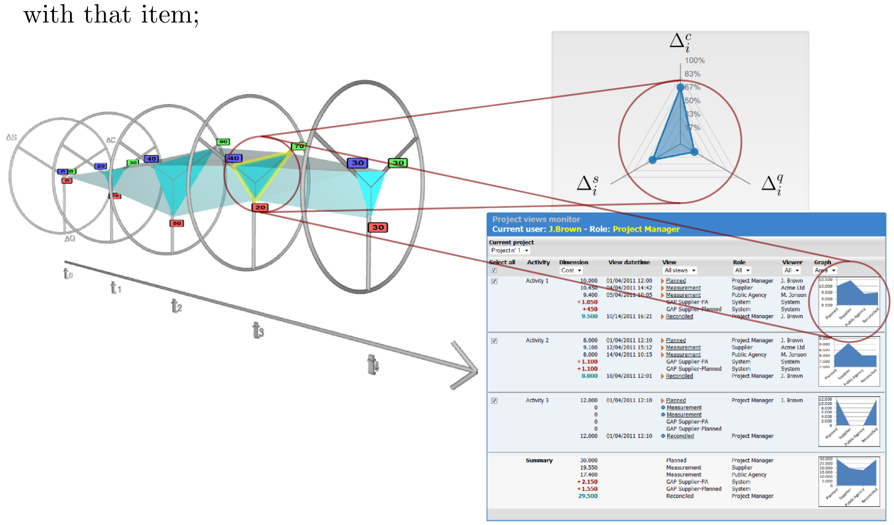


Figure 11. An example of details operation on 3DRCs.

– *Time zoom*: this operation is useful when the user is interested in a shorter time interval than the one currently visualized. The interval of interest can be selected by dragging the mouse over a horizontal slice of the 3DRC. The operation cuts off the time intervals complementary to the selection and stretches the selected slice over the whole result view. The subset of items included in the selection is visualized with a larger spacing, thus allowing the user to have a more detailed view. Further zoom operations are possible on the selection.

– *Zoom*: this operation allows to zoom in or zoom out the 3DRC to navigate inside of it. The operation is performed by rotating the mouse wheel or move two fingers apart/toward each other (see Fig. 12);

– *Filter*: it allows to select what activities and/or stakeholders must be considered for the visualization of the 3DRCs. The operation is performed by the 3DRC contextual menu;

– *Overlap*: the users can overlap multiple 3DRCs as discussed in section 4. The operation is performed by selecting at least two 3DRCs and click on the overlap button or touching at the same time two 3DRCs with long presses and performing a tap;

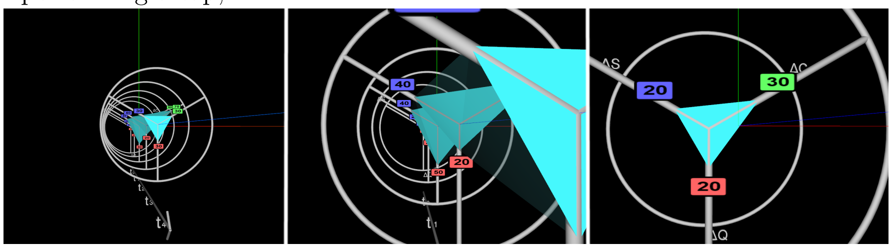


Figure 12. An example of Zoom operation on 3DRCs.

– *Split*: given a composite 3DRC, the user can decompose it in the original 3DRCs. The operation is performed by selecting the composite 3DRC and clicking on the unoverlap button or selecting by a finger the composite 3DRC and make a double tap on the composite 3DRC;

– *Color Coding Switch*: the user can switch on/off color coding of a 3DRC. The operation is performed by the 3DRC contextual menu (see Fig. 13);

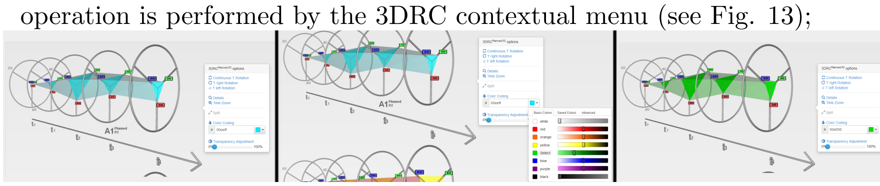


Figure 13. An example of the color coding switch operation on 3DRCs.

– *Transparency Adjustment*: the transparency degree of the selected 3DRC may be adjusted. The operation is performed by the 3DRC contextual menu.

6 Validation

We ran a user study aimed at recording users' subjective impressions in tasks related to the use of 3DRC. We measured the perceived usability of the system through a System Usability Scale (SUS)[8] questionnaire. The questionnaire is composed of 10 statements to which participants assign a score indicating their strength of agreement in a 5-point scale. The final SUS score ranges from 0 to 100. Higher scores indicate better perceived usability.

We recruited a total of 12 participants (8 female) among the university staff. The ages ranged from 37 to 49 (M = 43.2, SD = 4.2). Half (six) of them had some previous experience with project management. All of them were habitual computer users.

The tasks used in our experiment are listed in Table 2. The tasks were chosen in order to mimic a typical use of the system, and are mainly focused in the evaluation of the user's ability to gather information from the observation of 3DRC. The system was populated with the same data used for the samples shown in the previous sections. The tasks were executed on a *Dell OptiPlex 3010* workstation equipped with an *Intel Core i5* CPU running *Microsoft Windows 8.1 Pro* operating system, with a 21 inch LED display. The time limit for the completion of all tasks was 20 minutes.

Table 2 The tasks used in the experiment

Task	Description
1	Given the displayed 3DRC determine through zooming, 3D rotation or axis rotation: (1.i) the trend Δ_c, Δ_t, Δ_q; (1.ii) the general performance of consonance, including the points of maximum and minimum consonance.
2	Given the simultaneous display of two 3DRCs, determine through zooming, 3D rotation or axis rotation: whether there is some form of relationship between the consonance view of (2.i) different stakeholders on the same activity; (2.ii) same stakeholder on different activities; (2.iii) different stakeholders of different activities.
3	Given the union of two 3DRCs, determine through zooming, 3D rotation or axis rotation: whether there is some form of relationship between the consonance view of (3.i) different stakeholders on the same activity; (3.ii) same stakeholder on different activities; (3.iii) different stakeholders of different activities.

Before the session, each participant had a brief *induction* phase where one of the authors explained him/her the purpose and operation of the system and instructed him/her about the experiment procedure.

All participants successfully completed the three tasks and their sub-tasks. The average task completion time was 13.3 min (*s.d.* = 4.3 min). The scores of the questionnaire calculated on the responses of the participants are shown in Table 3. As reported in the table, the results of the survey range from 62.5 to 92.5, with an average value of 75.6. This value is for a good level of satisfaction[6].

Table 3 Scores of the SUS-like questionnaire for user satisfaction

Username	Score
participant 1	80
participant 2	75
participant 3	90
participant 4	72.5
participant 5	70
participant 6	62.5
participant 7	80
participant 8	70
participant 9	75
participant 10	70
participant 11	92.5
participant 12	70
Average	75.6

The following considerations have emerged after a brief interview/discussion with the participants involved in the experiment to understand what aspects of the tool were of help in the execution of the tasks:

Task 1: All users have emphasized how 3DRCs allow to instantly identify the points of maximum and minimum consonance.

Task 2: Participants have highlighted the usefulness of the 3D rotation and axis rotation (T-rotation) functions in order to examine the 3DRCs. The zooming function, generally, has attracted interest only for the ability to browse and explore the inside of a 3DRC. Great benefits have been gained in sub task (2.i) and (2.ii). For sub-task (2.iii) 6 out of 12 participants have been able to quickly identify the lack of relations.

Task 3: As above, 3D rotation and axis rotation functions have been deemed useful in interacting with 3DRCs. The same applied to the zooming function. Big benefits in identifying some form of relationship have been gained in sub-tasks (3.i) and (3.ii). For sub-task (3.iii) 7 out of 12 participants have succeeded in quickly identify the lack of relations.

In general, the participants emphasized that the union (overlap) of two 3DRCs allows faster identification of potential relationships. Although, in some cases (8 out of 12 participants), the ability to view simultaneously both individual 3DRCs and their ovelapping was reported to be of further assistance. The T-rotation was particularly effective in solving the problem to display hidden surfaces without the need to change perspective.

7 Conclusions

In this paper we have presented a visualization technique and its implementation, called 3DRC Tool, that addresses the prevention and proactive handling of the potential controversies among project stakeholders. The approach, based on the 3D Kiviat diagrams, uses radar charts to represent the points of view of stakeholders about the execution of the project activities and the trends of the project consonance. 3DRCs are composed from radar charts to show the gap variations over time; moreover, the overlap operation provides functionalities to merge and compare different 3DRCs.

The novelty of this work is the application of a 3D graphical visualization technique to the specific problem of the Project Management concerning the dispute management. Some strengths of 3DRC are the possibility of analyzing the relationships among activities, understanding how different stakeholders interact with each other across the time on the same activity (or subset of activities), comparing different activities and eventually discovering some hidden correlations between them.

The method has been validated in the context of a project aiming at the realization of a sensor network for the monitoring of environment variables and fire prevention[26] obtaining satisfactory results in terms of prevention or immediate handling of potential disputes. We believe that the introduction of the 3DRC technique offers additional benefits to stakeholders about real time project monitoring giving a visual and more immediate perception of the project trends not easily identifiable from tabular data.

Future work will focus on continuing to test the effectiveness of the 3DRC technique on real projects although this requires a long time. Currently, a validation phase against the SMART-TUNNEL project (involving the realization of an e-logistics system for the Italian ports) is in progress. The preliminary ideas of

3DRC gained interest from certified Project Managers and practitioners encouraging us to continue the research. Other future work include the implementation of a full FLUID interface to provide an increasing usability and a full user experience on touch-systems, and the testing of new gestures designed for touch systems through the use of case studies.

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