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Abstract

Multiple Criteria Decision Aiding (MCDA) is a domain of Operations Research and Management Science mainly devoted to the development of methods, techniques and tools aiming to help decision makers in complex decision processes. This paper describes DecSpace, a framework to explore a wide range of methods of that kind. DecSpace is a web-based framework, making it possible to explore solutions for problems involving one or more methods. Persistent workspaces also make it possible to reuse solutions. In this sense, DecSpace is intended for use in teaching and researching in MCDA methods, as well for professional use as a Decision Support System for engineering and management scenarios where decisions based on those methods are to be considered. DecSpace has an open architecture, making it possible to use methods implemented locally, fully integrated as part of the local application, or methods available from remote servers, if exposed as web services.

Keywords: *Multiple Criteria Decision Aiding; Decision Support Systems; Web application; User experience.*

1. INTRODUCTION

Multiple Criteria Decision Aiding (MCDA) is a domain of Operations Research and Management Science mainly devoted to the development of methods, techniques and tools aiming to help decision makers in decision processes.

The main purpose of MCDA methods is to support a decision maker during the decision aiding process, while taking personal preferences into account. The use of this kind of methods can be challenging for those that are not experts in MCDA.

The number of MCDA methods and publications are increasing, and with it so does the software available, including spreadsheets containing method computations, web or smartphone applications, contributing to the increase use of these methods amongst researchers and professionals.

DecSpace is a framework for the use of MCDA methods, with the clear objective of lowering the complexity of using those methods. The main goals are the ability to reuse existing open reference implementations that already exist for some methods (which is the case for many of them, therefore they do not need to be re-implemented), the provision of an interface that welcomes users from diverse backgrounds and with different levels of experience with MCDA and to provide a web-based framework, making the best use of the cutting-edge related technology (Barbosa, 2017).

This paper is organized as follows. Section 2 introduces a brief overview of MCDA. Section 3 presents some existing decision support tools. Section 4 is devoted to present DecSpace. Section 5 introduces the DecSpace domain model. Section 6 provides a demonstration of DecSpace. Section 7 presents some concluding remarks.

2. OVERVIEW OF MCDA

MCDA is useful for facilitating in decision situations that involve several criteria, while the preferences of the decision makers are taken into account. Adopting an MCDA approach is pertinent in several domains, such as healthcare (Marsh, Goetghebeur, Thokala & Baltussen, 2017), environment (Huang, Keisler, & Linkov, 2011; Linkov & Moberg, 2012), finance (Doumpos & Zopounidis, 2014; Zopounidis & Doumpos, 2002), energy management (Mardani et al., 2017), among many others (see, for example, Guarnieri, 2015; Mardani et al., 2015).

The literature in this field is rich (for the bases of MCDA, see Roy & Bouyssou, 1993; Roy, 1985, 1996; for an overview of the field of MCDA, see Greco et al., 2016; and for research trends, see Ehrgott, Figueira & Greco, 2010; Zopounidis & Pardalos, 2010). Indeed, several researchers have proposed methods and techniques for aiding decision makers to handle decision situations effectively and efficiently, intervening in all phases of the decision process (i.e., representation of the problem situation, problem formulation, evaluation model, and final recommendation) (Bouyssou, Marchant, Pirlot, Tsoukiàs & Vincke, 2006, chapter 2).

Generally, a set of objects, actions or alternatives (hereinafter called actions) are assessed according to a multitude of characteristics, also called attributes, considered relevant for the decision situation at hand. In the case of the value sets of these attributes are preferentially ordered, they are called criteria (Roy, 1996, chapter 9). For instance, one can face decision situations dealing with the choice among actions (e.g., choosing a car, see Bouyssou et al., 2000, chapter 6), or the rank of actions (e.g., ranking universities, see Corrente et al., 2017), or the classification of them into predefined

categories (e.g., classifying countries in terms of governance performance and efficiency, see Costa, Figueira, Vieira & Vieira, 2017).

Decision making is present in our lives, from simple decisions to complex decision situations, usually involving conflicting criteria. In particular, for organizations, public or private, in several sectors, decision making is crucial for their business. Thus, managers (or stakeholders) need the support offered by MCDA methods to make effective decisions. Indeed, an MCDA approach can be suitable even for dealing with decisions related to complex systems presented, for example, in industrial processes, public policies, and supply chain management.

An MCDA approach allows to structure and have a better understanding of the decision situation at hand and handle it in a logical and systematic way. In addition, an interaction with the stakeholders enables a transparent process and a deeper knowledge of the whole decision situation. Besides that, having tools to support the decision aiding process is an added value. In practice, the MCDA methods need to be supported by software tools or decision support systems (DSS). Indeed, having DSS is pertinent to facilitate the collection of the data, all computations and the analysis of the results (including sensitivity and robustness analyses). DSS are relevant to all actors that participate in the decision aiding process, in the sense that DSS can facilitate the application of the methods and techniques, even to those that do not have experience *a priori* with MCDA, providing an easy way of modeling the problem, and visualize the data, processes, and results (Liu & Stewart, 2004). Besides the applicability and relevance of MCDA for several domains, this reinforces the significance of the development of methods and their appropriate implementation.

3. OVERVIEW OF MCDA TOOLS

The application of MCDA methods needs to be supported by adequate software. Numerous software solutions have been implemented to support the application of MCDA methods in real-world decision situations, but very few offer a great solution for visualization purposes.

To really understand the problem, we need to comprehend the visualization tools identified, using the following state-of-the-art web technologies, utilized to achieve the promise of interactive browser-based system visualization application. Each tool is examined from a visualization representation, meaning that we are looking for the best evaluation of the objectives, architecture, technology applied, and main application functionalities. This analysis helps to figure out what are the required characteristics of these software programs and what are the main aspects that they are lacking, which this new framework tries to overcome, in order to make a very inclusive implementation.

*D*iviz is an accessible software tool for building, executing and sharing complex workflows formed by MCDA methods, developed by the Decision Deck Project (Meyer & Bigaret, 2012). One of the

main features is that it supports the construction of academic MCDA methods, by combining several elementary calculation elements, offering the tools to consolidate new decision methods, in every implemented language, without having to rewrite them (Meyer & Bigaret, 2012). This design makes possible to efficiently integrate additional methods without great struggle. The design of the MCDA workflows is performed by an intuitive graphical user interface, allowing the user to execute it in order to obtain various possible outputs of the algorithms. These calculations are implemented on high performance computing servers by using the XML Multiple Criteria Decision Aiding (XMCDA) web-services. After the execution of the workflow, the outputs of each component can be viewed and analyzed by the user, allowing for a complete concept of the algorithm, while the parameters can be changed.

Diviz can also be a useful tool to compare the outputs of various methods and algorithms on the equivalent input data, with a feature to export and import any workflow, with or without the data, as an archive, that can then be shared with any other user. In terms of architecture, *diviz* can be represented by a three-tier application composed of the following tiers: the client, graphical user interface, the component entering the XMCDA web services, reaches the necessary resources and other external platforms, and the server, plans and controls the execution of the workflows, divides the computations through the dedicated web services and returns the output of the executions to the client.

D-Sight provides a selected amount of Strategic Solutions, with a specialization in the areas of MCDA and user-friendly software development (Hayez, De Smet, & Bonney, 2011). This system provides responsiveness analyses to easily visualize and measure the impact of changing factors on projects. By developing a unique mathematically validated methodology for multi-criteria analysis and bound it in a state-of-the-art software, it is possible to see all relevant data under the model of a graph or chart, or even automatically see every likely scenario.

D-Sight implements standard functionalities such as the methods PROMETHEE I and II, the GAIA visualization tool, sensitivity analysis (including, for instance, the walking weights or the decision maker's brain), and a Group Decision Support System. Providing a standard framework that allows conducting a deep analysis process, with the purpose of finding the best compromise solution, justify decisions and, consequently, save time. *D-Sight* is programmed in Java. Its structure has been designed following the best practices in programming to guarantee easy maintenance and evolution. The data layer is clearly defined enabling easy access for external applications, integration, and external access have been made easier thanks to the plugin system Open Services Gateway initiative framework.

Expert Choice is a real-time decision-making software that consolidates cutting-edge technology with time-tested mathematics to provide a well-informed decision (Barfod, 2014). The objective is

to promote a collaborative, straightforward, and accurate approach to complex decision-making, changing complex and mathematically incorrect decision processes into a repeatable, understandable, and valid process. With an easy-to-use software and minimal training, leverages decision-making practices that are established to deliver more optimal decisions.

Expert Choice has several options in the visualization sector that can be used to view sensitivity analyses results, while focusing on features like establishing explicit decision goals, by using business demands and communicate the decision goal to all the evaluators, set objectives and provide alternatives to evaluate them, leverage the expertise of subject matter experts in decision making by designating specific roles, cooperate either real-time or anytime with teams, partners, and customers all across the world to gather their intuition and hard operational data, synthesize the team's intuition, and hard operational data easily, use the outcomes to make better decisions to meet your demands and implement decisions with more confidence.

After the analysis of the three selected tools, which are solid and offers better possibilities for presenting the best usability and interface than the others available. Many of the remaining tools have very interesting features, but none offers the complete experience. It is important to point that for some tools a license is required (some offer a demo), that is expensive for the average user. The analyzed features are presented in Table 1.

	diviz	**D-Sight**	**Expert Choice**
1 Open-source	y		
2 3D visualization techniques			
3 Data files import and export	y	y	

Table 1 – Studied tools features

The application of MCDA framework can be challenging for users who are not experts in MCDA methods. There are not many frameworks that focus on usability or user experience, making it very difficult to use. Nonetheless its application is becoming more important, so the need to create a new application surged.

4. DECSPACE OVERVIEW

DecSpace is a framework that offers MCDA methods for the user to solve problems of different kinds within just one application that is compatible with all web browsers. In this section, the original prototype is analyzed from different perspectives, taking into consideration the architecture, features and technologies.

DecSpace provides the following use cases as illustrated in Figure 1:

- Types of Users: There are four types of users with different permissions: the developer has the objective of adding new methods; the administrator manages all registered users and projects; finally, registered users and anonymous users, the difference between them is that registered users have an account and their work is persistent;
- User login and registration: The first step to use the application is to provide a username, an email, a password and a privacy setting, to access the user personal area, it is possible to enter as a guest, but some features are removed from the experience, as a logged user it is possible to reset the password or log out;
- My Projects: This area allows the user to manage projects, to create a project, and to choose if the project is public or private, the following fields identify each project: Name, Creation Date, Last Update and Privacy Setting, for each project, open, duplicate and delete features are available;
- Public Projects: This area contains all public projects that are shared by users, the following fields identify the projects: Project Name, User name, Creation Date and Last Update, for each project, a duplication and open feature is available. The purpose of this area is to provide complete projects to all users;
- Method Catalog: All the methods created are in this area and are divided in two categories, local methods, created by the developers of the framework, and remote methods, through simple object access protocol (SOAP) requests between the *diviz* server. It is possible to reuse all their different methods, each one as a description and an example to provide some help and information about each method;
- Workspace: This is the most important area, where all the technical work happens. As far as features go, it is possible to import and export a comma-separated values (CSV), XMCDA or javascript object notation (JSON) file, a zip file can also be added, containing a workflow that was already used, the workflows can be saved, refreshed, executed and deleted. Any method on the catalog is ready to be used, they can be dragged to the workspace and connected between themselves.

The proposed architecture is structured in three main tiers as presented in Figure 2. The objective is to confine most of the complexity to a single tier and restrain the interface details to another tier, which allows to focus on the usability and user interface:

- Client tier: The client tier consists of an interaction with the application tier to send user requests and after these requests are processed a response is returned to the client, which allows the user to perform the most various tasks the system has to offer. In terms of infrastructure, the interaction with the web server is done with simple HTTP requests;

- Application tier: The application tier defines the great complexity of the system, where most of the computational activity is performed. It acts as the server for client requests, by receiving and processing user requests sent by the client tier, and also carrying out the connections to the data tier. The location is a web server that executes the workflows and several MCDA methods;
- Data tier: The data tier is an entity that contains all the information of the application. It communicates with the application tier by receiving, processing and replying to the data requests. It is formed by a database and communicates with the application tier with the aid of the MongoJS library.

DecSpace implementation uses the Mean Stack approach, using the combination of the following programming languages and libraries that synergize well together, which simplifies and accelerates the development of web applications:

- MongoDB: It is an open-source cross-platform document database that provides high performance, availability and automatic scaling. MongoDB supports dynamic schema design, allowing the documents in a collection to have different fields and structures;
- Node.js: It is an open source development platform for executing event-driven JavaScript runtime environment, specially designed for building scalable network applications;
- Express.js: It is a minimal and flexible Node.js framework that provides a robust set of features for web and mobile applications, to help organize your web application into a model view controller (MVC) architecture on the server side;
- Vue.js: a progressive framework for building user interfaces, Vue is designed from the ground up to be incrementally adoptable.

Aside the Mean stack technology, Hypertext markup language (HTML) is used for designing and displaying the basic structure of the web pages; Cascading style sheets (CSS) for the visual style of the web pages; JavaScript for advanced handling on the front-end side of the application; jQuery is a concise and fast JavaScript library that can be used to simplify event handling for navigating the document.

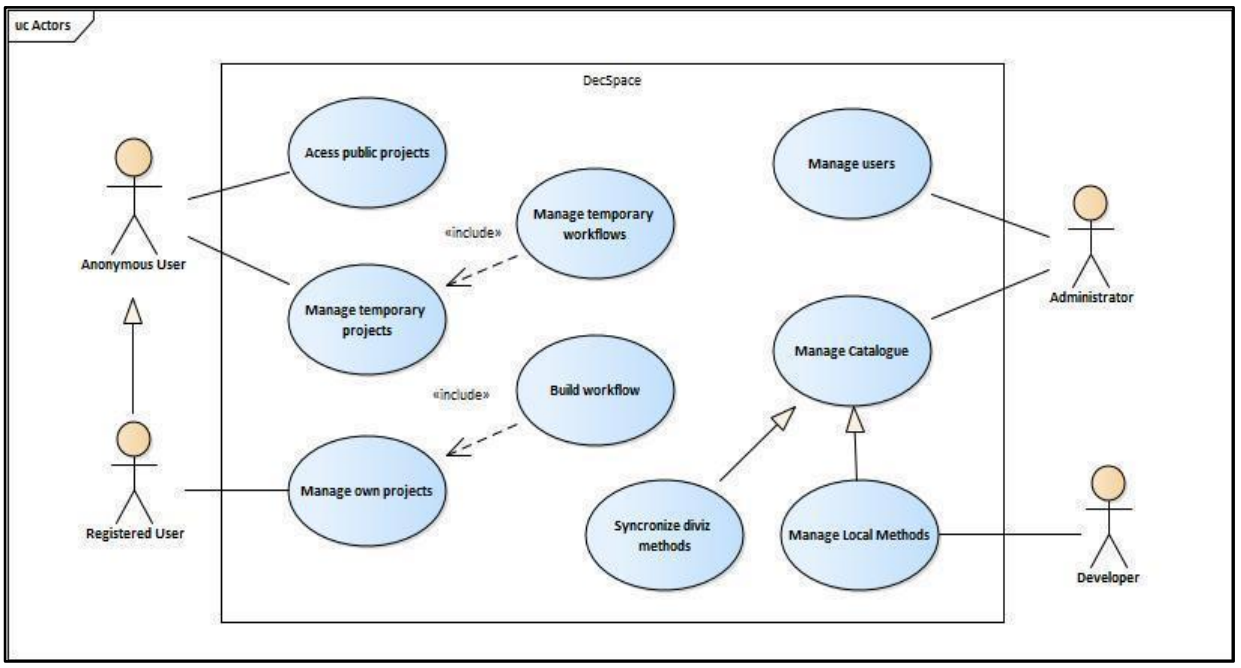

Figure 1 – Use Cases Diagram

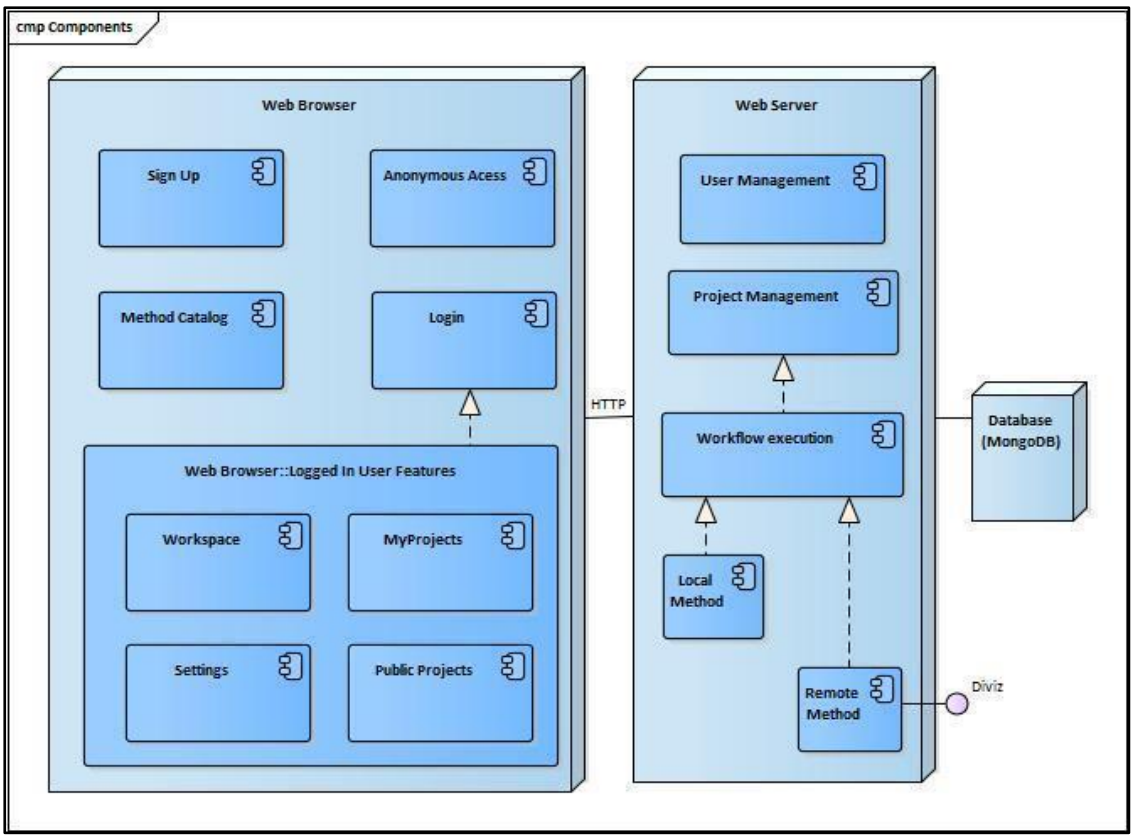

Figure 2 – Deployment Diagram

5. DECSPACE DOMAIN MODEL

The most consistent concepts and the relations between them should be described to better understand the need for this application, as represented in Figure 3. A user is identified by its email address (which must be unique), and must have an associated password, name and privacy setting. For each user, the date ofregistration, date of the last login, and if the user is currently online are also stored. This information is used to create an account. Private accounts do not let the administrator know when they are online, while public accounts provide that information. If the necessary fields are correctly fulfilled, then a new account is created. Logging in, using the email address and password, should grant access to the projects and data of the logged user. Certainly, the user should have the possibility of logging out after he finishes a work session. Registered users should be able to define several account settings, e.g., changing the password. It should also be possible to create projects and workflows anonymously, i.e., without signing up. After logging out of an anonymous account, the user cannot recover its information.

A user may own multiple projects, which are distinguished by their singular id. Projects have also attributed a name, owner, date of creation and date of last update (i.e., the last time the project was initiated), and it should be conceivable to create, open, duplicate and delete them. A single project may contain several workflows, which are singled out by their id as well. They also contain the date in which they were saved and, possibly, a comment made by the user. A workflow consists of various modules and connections between them. A module can be of two kinds: method or data (either input or output). Method modules are uniquely identified by the attribute “type count” and, as of the last version, there are six different types of local method modules that correspond to the available methods (Additive Aggregation, CAT-SD − Categorization by Similarity-Dissimilarity, Inquiry, Order By, Sort, and SRF), there is also a remote method that corresponds to all available methods in *diviz*. These methods can be executed outside of the application, which implies that there is not the need of implementing those methods in the platform, Decision Deck's XMCDA web services are algorithmic components or complete MCDA methods, which are made available online, through SOAP requests. The attributes of these methods correspond to their input data. Data modules are simply identified by their name and contain the data that was imported by the user or created by a method module. Another relevant feature is the importation of input data from the CSV, XMCDA and JSON formats, as well as the importation and exportation of workflows to the same formats. There should be a unique account that has the right of accessing information about the users and their projects and be able to delete them without their consent. This account should be used only by the administrator of the application.

All users should be able to access the most basic information about DecSpace, which includes a brief introduction of the application, the description of the methods, the frequently asked questions and a form for contacting the developers. All this information should be available from a menu or

navigation bar shown on every page of the application so that it is possible to quickly access any part of the website. Logged in users should be able to open every project created as "public" and change their contents, but not be able to save those changes since that right belongs to the owner of the project. Those users should also have the possibility of cloning those projects to their own account so that they can freely work with it.

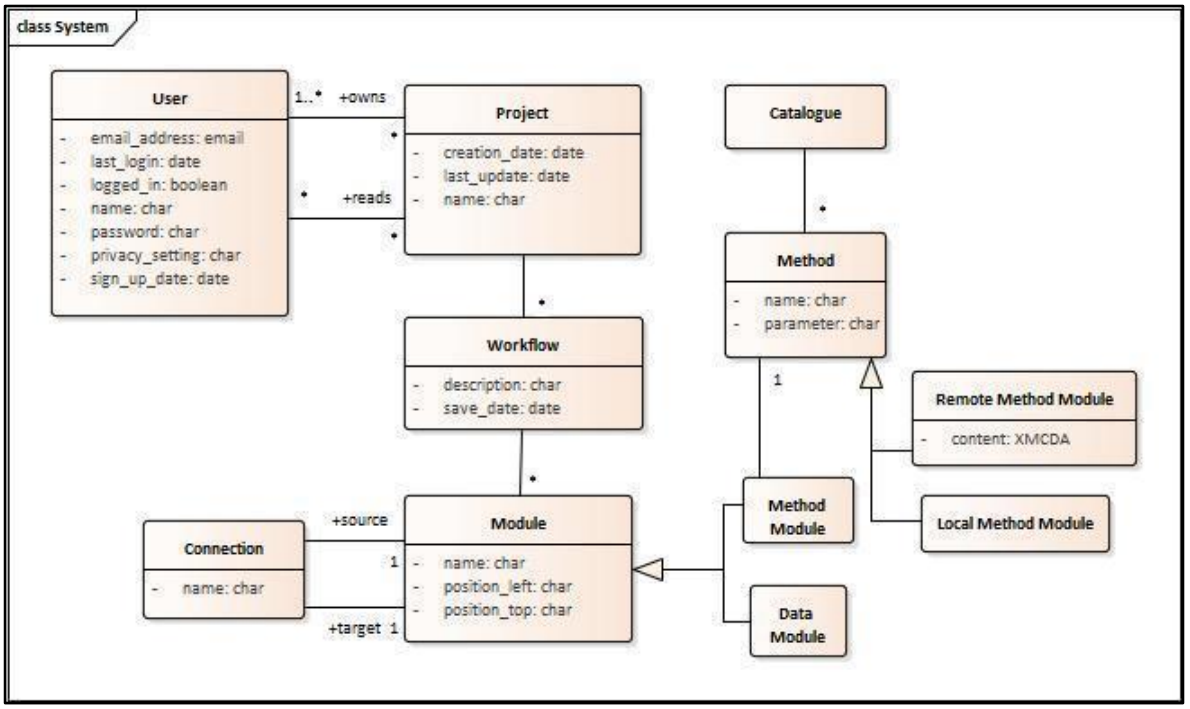

Figure 3 – Domain Model Diagram

6. DECSPACE DEMONSTRATION

The main workspace is where all the workflows are created, is quite intuitive with a drag and drop feature and a color scheme of the data input and output, and modules can be connected between themselves or to different data files.

Let us use an illustrative example of an application of the SRF method for demonstrating some features of DecSpace. SRF is an implementation of the revised Simos' procedure for the determination of the weights of criteria in the ELECTRE family of MCDA methods, proposed in Figueira & Roy (2002). It has been successfully used in various real-world decision scenarios in different areas (for a review of applications of the original and revised versions of Simos' method, see Siskos & Tsotsolas, 2015, and for some recent applications of the revised version "SRF", see, for instance, Doumpos & Figueira, 2018; Pinto et al., 2017).

The application of this method starts by associating a "card" with each criterion. The DM has to handle the cards in order to rank them from the least to the most important, while also inserting white

ones in order to increase the difference of importance of two successive criteria (or sets of criteria, if they are positioned in the same level). For determining the weights of the criteria it is necessary to provide the list of criteria, the ranking of the criteria and white cards, the parameter ratio *z* between the importance of the most important subset of criteria and the importance of the least important one, the number of decimal places (it can be set to 0, 1 or 2), and the type of weight value (normalized, non-normalized or both).

In the following example, the SRF module is being imported to the workflow, modules are represented by "boxes" with different inputs and outputs. The inputs can be inserted by the user or through a CSV or JSON file as displayed in Figure 4. In this case, the subject is the act of buying a car, so the decision situation at hand is choosing a car. For that, one could consider relevant criteria like consumption, price, safety, etc. The first step is then insert the name of the considered criteria, as shown in Figure 5. The second step is to handle the cards that correspond to the criteria in order to rank them from the least to the most important, while also inserting white ones in order distinguish the importance of two successive criteria, as depicted in Figure 6. An important feature is the "drag and drop" functionality that allows the user to rank the cards as it sees appropriate Finally, the last step is defining the ratio z, decimal places and weight type, as depicted in Figure 7. After this, the user can save or export the workflow, or run; if all is done successfully, the output module is generated, and the results can be examined (see Figure 8).

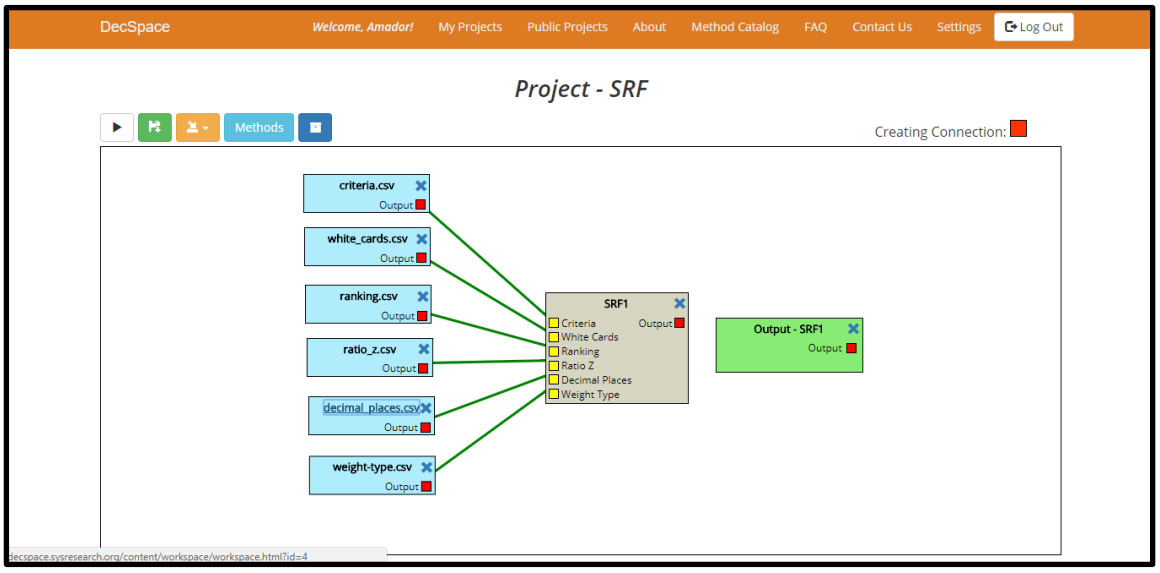

Figure 4 –SRF Workspace

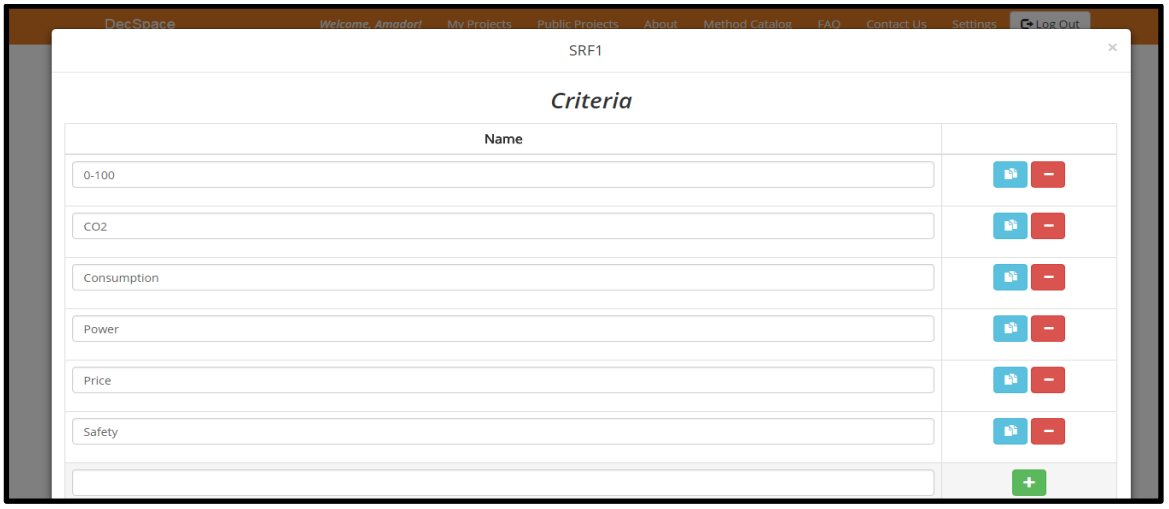

Figure 5 – SRF Criteria Input

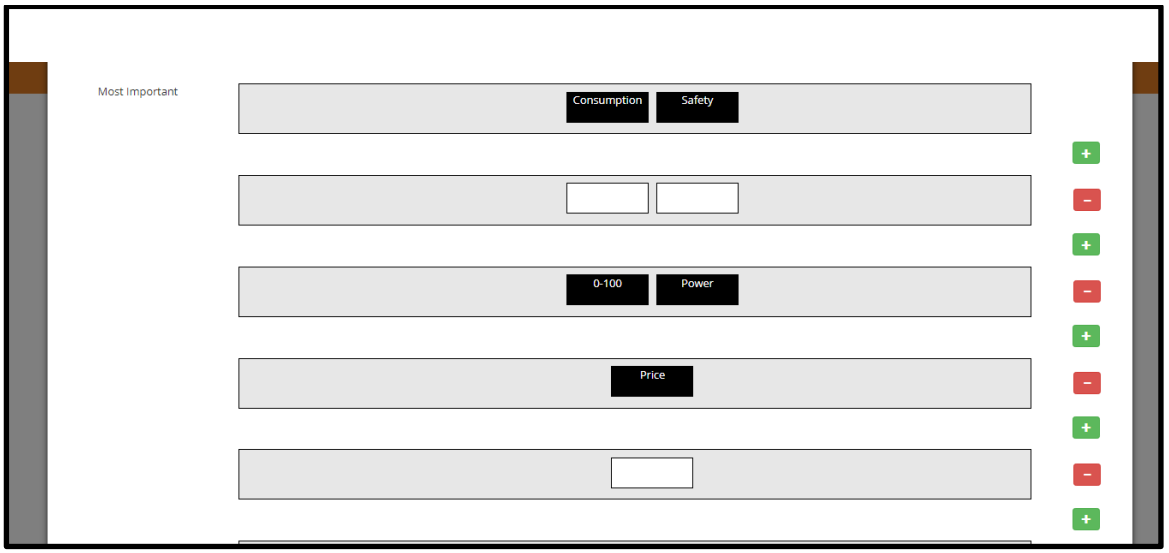

Figure 6 – SRF Ranking

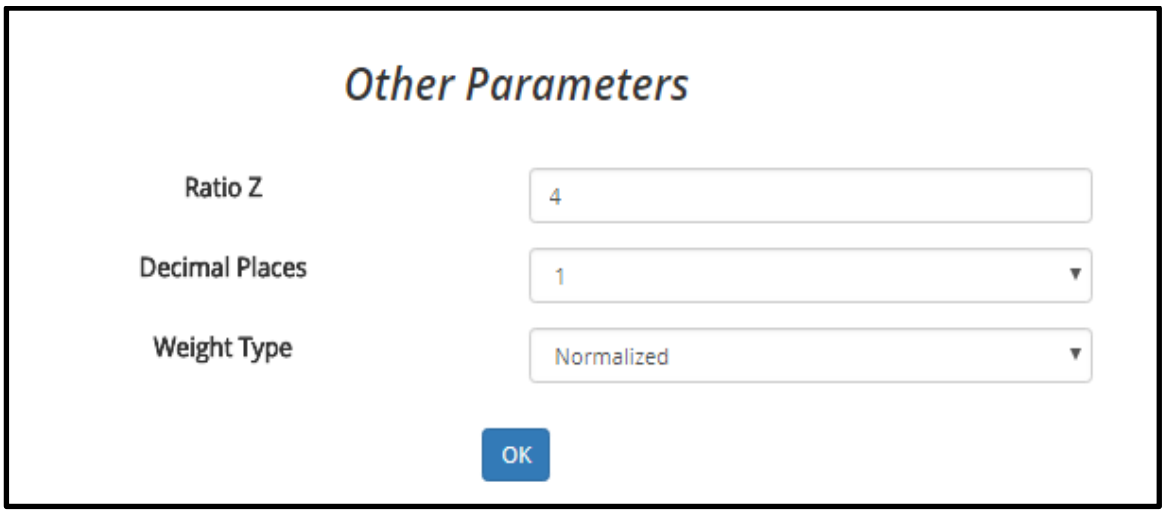

Figure 7 – SRF Other Parameters

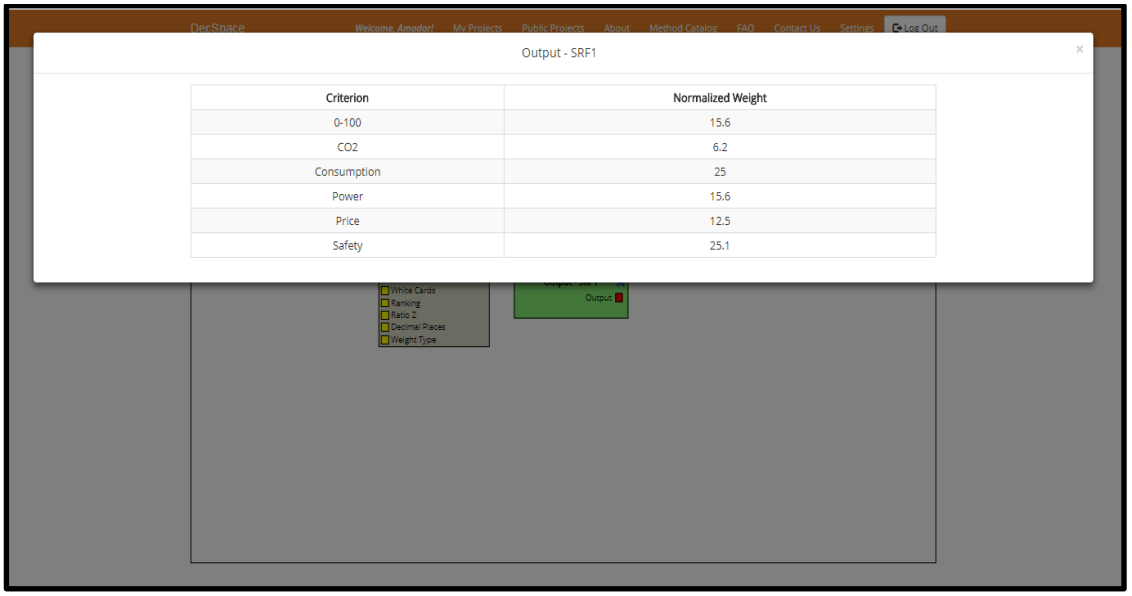

Figure 8 – SRF Output

7. CONCLUSIONS

The purpose of MCDA is to provide support to decision makers during decision processes with methods and techniques, as well as frameworks for computational support. Handling these frameworks can be challenging for users who are not experts in MCDA methods. For that reason, requirements related to usability and user-friendly issues need to be taken into account in the development of these frameworks.

In this paper, we proposed a new approach to the MCDA phenomenon with a framework that employs forefront technology, well-studied usability and user interaction techniques. The fundamental objective is to support a decision maker to structure and to better understand the decision problem at hand.

DecSpace is a web-based framework that provides MCDA methods and allows to create projects with multiple workflows using one or more of such methods. Indeed, an increasing number of MCDA methods are available, implemented locally or remotely exposed by *diviz* server and as web services. We show that DecSpace is intended to be a user-friendly solution for supporting the decision processes in different scenarios, for both non-expert users and MCDA expert users. We presented the main features of DecSpace and highlighted that is focused on the usability and user interface. Future work relies on improving usability and user experience issues.

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