

Web-based framework for real-time collaborative decoration design.

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SUMMARY: *In this paper, we present a web based framework for interior decoration that merges Semantic Web with Web3D technologies in Real Time Communication environment. We have developed an extensive ontological framework for the description of indoor areas from an interior design perspective and we have incorporated a SWRL and a SPARQL framework to enable automatic decoration recommendations in 3D format in browser. Our room designer is fully interactive, and customizable in real time environment with the assistance of the WebRTC. Last but not least, our experimental results showed that even inexperienced users with the domain of interior design, were able to successfully deal with the proposed ontology in terms of usability and suitability.*

KEYWORDS: *Semantics, OWL-DL, SPARQL, SWRL, X3DOM, WebRTC, Online decoration*

1. INTRODUCTION

In this paper, we present our work for the Decoration Ontology (DECO) project, a four-year project funded by the Operational Program "Education and Lifelong Learning", Archimedes III and EU. Within the DECO project, we have developed an extensive ontological framework for the description of indoor areas from an interior design perspective, incorporating all possible relevant aspects of an area. We have incorporated an SWRL framework to enable automatic decoration recommendations for designers and customers. The system also includes a SPARQL subsystem, allowing potential customers to specify their needs and requirements, which are later used to query and access proposed solutions. The entire platform can be accessed via a web interface, and also incorporates a visualization component, based on Web graphics technologies. Our work extends the experience of creating and modifying the interior space by adding semantics and communication capabilities between its users. Such real-time communication and interaction capabilities, benefit users that seek a complete room visualization solution without installing any additional program, classifying our application as an alternative and new approach in the field of interior design.

2. BACKGROUND & MOTIVATION

The Semantic Web comes with the promise to change our daily life by taking advantage of the present information found on the Web. Its main goal is to add semantics to these hidden data in such a way that machines can both understand and reason about their content (Berners-Lee, Handler, & Lassila, 2001). Today, ontologies and ontology-based systems appear as the nodal point for the development of potent and profitable Internet commerce solutions. Semantic Web has a much higher influence on e-commerce and e-work applications than the current Web, showing them the way to access a wide range of information about business, economics, analytics, etc. Such domains will be more prominent compared to others in the near future, since they have already received improved efficiency and better optimization of their data thanks to appliance of semantics.

The most important part of information retrieval and usability design in Semantic Web applications is their query formulation process. SPARQL is the most widely known query language for exploiting the information found in relational databases, making use of typical tables filled with RDF triples or most advanced triple-store database systems. Moreover, a three-dimensional visualization of a product is definitely a crucial advantage of any application compared to its plain image or 2D representation, since the user receives an -as reliable as possible- representation of its own room space. This fact was further strengthened by the rapid growth of various Web3D technologies that provide the customer with the ability to get involved in product's design process. So, today users can freely manipulate and customize the products they are interested in, through convenient and straightforward 3D visualization tools that emulate real world actions (Hughes, Brusilovsky, & Lewis, 2002). These new experiences enabled by Web3D, didn't change the face of the classic World Wide Web, remained independent of the underlying platform, and their only requirement was the partial use of a browser in a typical computer (Chittaro & Ranon, 2007). Finally, World Wide

1 Web is able to provide Real-Time Communication (RTC) services between users' browsers all around the Web thanks
2 to WebRTC. In the last years various applications have been developed using WebRTC for a diversity of domains,
3 utilizing some of its several APIs for text messaging, video calling, conferencing, online gaming, etc.

4 Searching for recent research works which have taken advantage of interior decoration solutions like
5 Autodesk HomeStyles (Autodesk HomeStyles, 2016), Roomsketcher (Roomsketcher, 2016) and Planner 5D (planner
6 5D, 2016), we noticed that their main disadvantage lies to inclusion of Adobe Flash Player, which should be
7 preinstalled on user's computer. Such applications may provide the ability to store the designed interior space in a
8 format that resembles JSON, but unfortunately it cannot be used elsewhere by the user except within his application.
9 Another application that we found in our research is the Roomstyler (Roomstyler, 2016) which provides 2D
10 representation of an interior space with the ability of "Screenshot" in 3D format Also, the IKEA home planner (IKEA
11 home planner, 2016) is one more application which operates with the assistance of a standalone browser plugin.
12 Afterwards, we meet solutions for WebRTC-based multi conferencing software or plugins. Software like Intel
13 Collaboration Suite for WebRTC (Intel Collaboration Suite for WebRTC, 2016), Kurento (Kurento, 2016), Licode
14 (Licode, 2016), Jitsi (Jitsi, 2016) are some of the media servers or APIs which are able to add real-time communication
15 to the applications. However, such multiconference solutions were never integrated with a CAD environment to form
16 a multiuser design solution environment.

18 **State of the art technologies**

19 Several solutions about interior design architecture can be found in literature, where the majority of them applies
20 to Semantic Web, Web3D and Real-Time Communications' domains. In paper (Stamou & Kollias, 2005), authors
21 demonstrated the practicability of ontologies within applications, along with an indicative categorization according to
22 their scope of use. In short, ontologies successfully achieved the categorization of products within catalogues,
23 categorization of web-services and identification of unique products. A notable work in paper (Makris, Karatzoulis, &
24 Tzouvaras, 2007) presented an Intelligent DIY (Do it Yourself) system for design that was based on ontologies and
25 three-dimensional (3D) visualization techniques. The implemented system aimed to provide a more realistic
26 visualization of its products, by including an online product configuration tool backed by a three stepped OWL
27 ontology for insertion of object's 3D parts, selection of the desired texture and storing the 3D animation for future use.
28 Also, a Configurable Electronic Shop Platform in the form of a web-based application (Karatzoulis, et al., 2006)
29 allowed users to assemble furniture parts of various products. These parts could be anytime stored in a specific system
30 repository maintained by the manufacturer of the end product. In paper (Tsamoulatidis, Nikolakis, Tzouvaras, &
31 Strintzis) was developed a 3D interactive system for the semantical description of the physical relations between
32 objects in a room. Its interior design concepts were contained into XML Topic Maps (XTM), giving users the ability
33 to build a 2D design of a room which was afterwards translated to its relative Web3D model in VRML (Virtual Reality

1 Modeling Language). A more recent work (Lee & Jeong, 2012) put forward an interesting proposal for the definition
2 of a unified architectural environment. This environment provided a common building plan for all workmanships,
3 where each one was able to visualize only these elements that correspond to its profession. The proposal was built
4 around an OWL ontology that encompassed all aspects of the building process -from conceptual elements to design
5 elements- and a set of ontological descriptions for the presentation of X3D models in a VR environment.
6 Works which presented in (Rolland, Yvain, Christmann, Loup-Escande, & Richir, 2012) showed that Web3D
7 applications keep gaining ground compared to their 2D or pseudo-3D alternative solutions. One of them was “Caidou”
8 had the opportunity to visualize a 3D artificial representation of a 2D object, while the outcome could be anytime
9 exported to a PDF document in PDF3D format. In paper (Kapetanakis, Spala , Symba, Mamakis, & Malamos, 2010)
10 was presented an architectural design mechanism for the automated conversion of SVG (Scalable Vector Graphics)
11 indoor plans to their corresponding X3D representations, taking into consideration the directional and scaling variables
12 of these scenes and their contents. A similar approach was also adopted in (Kontakis, Steiakaki, Kalochristianakis, &
13 Malamos, 2015) , where the design of the room space was taking place through a convenient SVG environment, backed
14 by an ontological editor and an XSLT (Extensible Stylesheet Language Transformations) transformation algorithm.
15 Finally, many works are querying an ontology with SPARQL or SQWRL to boost the search capabilities with multi-
16 criteria search engines. Work such as (Wang, Lv, Wang , & Wang, 2008) described the method of content-based
17 retrieval in Semantic Web, where the model was based on the axiom that similar models may partially share the same
18 semantics. The approach followed was a mixing of clustering and feedback methodologies for the correlation of the
19 three dimensional models which were the individuals of an ontology. The proposed system was able to successfully
20 return all the results to the user, where the irrelevant ones were skipped and user was pointed to the nearest cluster.
21 The implemented system made use of OWL language and Jena Framework as its reasoning tools, while SPARQL
22 (SPARQL Query Language for RDF, 2008) language was deployed to assist the overall query process.
23 Besides 3D modelling and presentation systems, SPARQL solutions can be found in automated reasoning and interior
24 decoration areas. A mixing of AJAX, SVG, JSF, RDF, OWL, SPARQL, Jena technologies and DL reasoners gave
25 birth to an automated reasoning system named SMART (De Leon Battista, Villanueva-Rosales, Palenychka, &
26 Dumontier, 2007). It was designed to synthesize and validate semantic queries, represent them through a useful
27 graphical interface and map DL queries to SPARQL language.

28 Seeking efficient applications for the area of Real-Time Communication and collaborative environments we
29 carried out a search on the Internet for programs and tools dealing with such domains. Authors of the paper
30 (Panagiotakis, Kapetanakis, & Malamos, 2013) present the real-time communication over the Web and introduce an
31 innovative architecture with video and chat capabilities. Their work also provides a web-based implementation with
32 video streaming and chat features without the need of any plugin installation. With the passage of time, however, there
33 were also applications that integrated WebRTC (Web Real-Time Communication) capabilities within three-
34 dimensional virtual worlds for educational purposes. The majority of them dealt with the composition of a 3D

1 collaborative environment for educational that supported video calls, text messaging and the capability to select, insert,
2 and manipulate 3D objects in an X3D scene using the Data Channel of WebRTC. Such a unification of Communication
3 and Graphics fields is evident in (Andrioti, Stamoulias, Kapetanakis , Panagiotakis, & Malamos, 2015), where
4 X3DOM framework was merged with WebRTC technologies in order to constitute a virtual 3D collaborative
5 environment for the cooperation of web peers at real time, while at the same time, these peers were able to manipulate
6 the three-dimensional scene without the use of plugins. On the other hand, WebRTC was also found to be ideal for
7 immersive video conference experiences, since recent demonstrations (Web Real-Time Communication 2014
8 Conference in Munich, 2014) showed that the implemented virtual worlds could be further enhanced with real-time
9 social media connections, such as the Facebook, Twitter, YouTube, Spotify, and email as well.

10 **Motivation**

11 Our vision to combine the aforementioned technologies into a single real-time web-based collaboration
12 application led us to the espousal of WebRTC. This technology allows interconnected users of a specific website to
13 create groups in order to interact with each other. Our application enhances this interaction by providing video streams,
14 text messages and the sharing of a common 3D room design between the participating users and as a result enables
15 WebRTC-based multi-party conferencing. Furthermore, we extend the capabilities of the 3D interior or room designer
16 to a fully interactive, customizable in real time environment. Moreover we enhance our designer with a
17 recommendation system supported by a semantic triple-store repository of designs pre-stored by experts and retrieved
18 by SPARQL queries.

19 Our work provides Semantic Web solutions to interior decoration domains according to users' desires. Such
20 users are divided into several roles and are able to make multi-conference calls in numerous different "Sessions".
21 These "Sessions" mix the real-time communication with 3D representation of a room space. Each participant has the
22 ability to modify any 3D item and notify the rest of users about this change. The data integrity of communication
23 channel is secured via HTTPS protocol which supports Session Traversal Utilities (STUN server), allowing an end-
24 host to expose its IP when located behind Network Address Translation (NAT). This feature enables the Interactive
25 Connectivity Establishment (ICE) and helps devices to connect to each other under different networks. Moreover, the
26 same signaling server (socket.io) under Node.js is used for messaging, chat and video calls. No other device or API
27 was used for the creation of our MCU (Multipoint Conferencing Unit). All stream messages go through the MCU
28 server, resulting to the reduction of stream traffic and allowing a wide range of devices (laptops with any operating
29 system, smartphones, tablets, etc.) to take advantage of our web application.

3. PREVIOUS WORK

Ontology

In the recent past we developed our own interior design ontological framework in XML format (Malamos, Sympa, & Mamakis, 2009) which was later enriched with an ontology according to the specifications defined by the OWL-DL language. Experts in the area of interior decoration contributed to the requirement analysis and the standardization of the interior design concepts in a suitable form for ontology description. With the guidance of these experts, we followed the specific rules and finally we developed an ontology with appropriate structure and parameters. Their recommendations and research data have been collected and unified into a single deliverable¹ publicly available. DECO is an ontology implemented in OWL-DL language which deals with a single room space each time. Every room space is treated as a separate ontology consisted of the physical objects of this space and the annotation of the qualitative and quantitative characteristics of these objects and their corresponding space.

For the needs of our application we narrowed down the possible room spaces to the two most widely used interior spaces of any common residence, which are the "Bedroom" and "Living Room". DECO was slightly modified in order to keep up with the requirements stemming from these two spaces. Firstly, it was deemed crucial a classification rearrangement for the sufficient support of these two room spaces, as well as the addendum of additional physical objects in the form of OWL classes, such as Carpets, Placemats, Sculptures, Curtains, etc. Secondly, there was a significant increase in the number of properties in order to properly define the characteristics of the newly added physical objects. DECO ontology defines a number of distinct classes beneath owl:Thing, the root of every OWL ontology. These classes have been implemented under careful research on the field of interior design and decoration, in order to fulfill the needs met by the room spaces which DECO has to deal with. For that reason, the four major classes mentioned in paper (Kontakis, Steiakaki, Kapetanakis, & Malamos, 2014) were defined as basic OWL elements.

Class name	Description
Content	contains all physical objects of a room space such as windows, doors, furniture, accessories and others. These objects are subclasses which describe groups to related objects.
DataTypesCandidates	contains the qualitative characteristics of an interior space. Each one of these enumerators contains individuals which used for the assignment of characteristics.
Room	contains the interior spaces like living room and bedroom available for annotation.

¹ http://www.medialab.teicrete.gr/archimedes/deliverables/D2_1/index.html

Structural	contains subclasses such as floor, walls, ceiling and other objects which are core objects of the interior space that are built-in and not movable.
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Table 1. Classes of DECO Ontology

DECO object properties aim to give the ontology fundamental relational functionalities by interconnecting classes with individuals. However, DECO datatype properties are used to link OWL individuals with typical data values. High significance is the "has a 3D Model" property of an individual of class "Structural", "Content" and "Room", which is a string containing the URI of an X3D model of this individual. This is important for the visualization feature of the platform, since these models are drawn from a local or network repository and composited into a VR representation of the room.

DECO Framework

DECO framework is a web-based interface that was implemented with the assistance of Apache Jena and SDB triple store module, enabling in this way its functionality as an online ontological editor. The usage of this framework by content providers will make easier the storage of their room spaces and objects as ontological concepts with the assistance of dynamically generated drop-down menus, which can be later queried via SPARQL language and being displayed according to users' desires. The whole process of room annotation is exclusively done from Jena framework, while the presentation and user interaction is assisted by various technologies like Java Servlets, JSP, JavaScript and CSS. The front-end of the application is implemented in HTML, where the users are navigated through a series of forms, in order to efficiently annotate a room space. The concepts used for the room space annotation and decoration are based on the DECO ontology.

This semantic web interface has mechanisms to store a room space with two different formats. The first one is the file-backed storage that acts as a dedicated RDF/XML file on the disk, which can be accessed anytime in order to view the current characteristics of this room space and change them according to the latest decoration ideas, fashion trends, or design aspects. The second one lies to the RDBMS-backed storage, where Model datasets are persisted in the form of statements on a MySQL database. This storage type is taking place through the collaboration of the Jena SDB triple store system and the underlying operations provided by a MySQL database.

These two mechanisms provide an easy-to-use and fast way to store a room space as an OWL ontology. Our wizard supports two kind of users for this procedure, Content Providers and Designers.

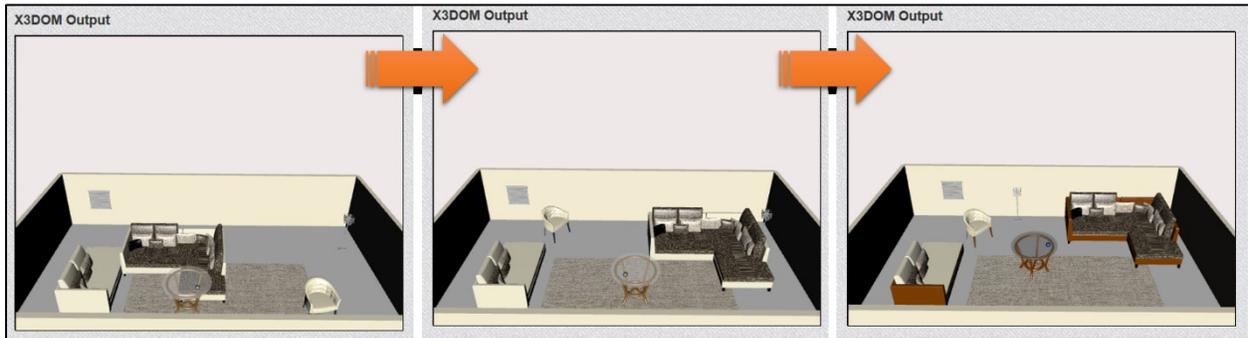
- **Content Providers:** The first step involves the population of the knowledge base with physical objects which can be used in rooms, such as a furniture or textile retailer. A content provider can make use of the web-based platform to assign individuals to classes and define their properties. Using the Web interface, a furniture retail company can insert a subset of items into an ontology and specify their characteristics. Object's materials,

1 colors and design style can be selected from the ontology, while a X3D model can be also provided by them
2 for incorporation into the knowledge base.

- 3 • **Designers:** Using essentially a similar approach and the same wizard to access the knowledge base, new
4 rooms can be created anytime since a designer can organize a fundamental room structure through platform's
5 web interface.

7 **DECO Web Editor**

8 Our 3D viewer -namely "DECO Web Editor"- is designed to graphically express the contents of the
9 knowledge base in X3D format. The virtual rooms are automatically constructed based on their ontological descriptors.
10 Users can then modify the scene according to their desires. The proposed platform aims to fuse this broad range of
11 technologies (OWL, SWRL, SPARQL, X3D and X3DOM) into a single integrated framework and lead to a practical
12 use-case application in the domain of interior design.



13
14 *Figure 1. DECO Web Editor*

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16 The implemented Web Editor is based on X3DOM framework, ensuring in this way its unimpeded operation
17 without the need of any plugin or pre-installed software. It is able to illustrate a room space which can be further
18 manipulated via various X3DOM features. Such features have been integrated into a utilitarian GUI and include the
19 most widely known operations met on typical 3D representation environments and the "Moveable" functionality from
20 X3DOM framework. The authored code makes use of X3DOM's core functions, allowing us to apply changes upon
21 an X3D scene with advanced manipulation and great flexibility capabilities.

23 **DECO Reasoning APIs**

24 DECO has two Reasoning APIs that take advantage of various reasoning mechanisms for the deduction of
25 additional OWL statements with the assistance of a rule-based system and property constructs.

- The **SWRL API** is able to infer extra entailments from the original OWL statements by applying a finite set of SWRL rules. These rules were authored with the Protégé-OWL editor and their scope is closely related to color theory and decoration properties. DECO framework integrated them as its rule-based system and made feasible their execution with the utilization of an external reasoner, namely the Pellet Reasoner. We have implemented and tested about 100 rules. The implementation of SWRL rules took into account two interior design textbooks on color theory (Chiazzari, 2005) (Chinn, 2007). These rules comprise aesthetic proposals based on the color of the floor, which are deducted and tallied to various X3D objects, providing to users the ability to place any of the proposed objects in the X3DOM scene.
- The **SPARQL API** is based on the Jena Model Interface and is responsible for the execution of queries directly upon the OWL knowledge base. Users define their desired criteria for searching, which are in turn composed into a single query that retrieves the required information from an OWL-DL ontology.

4. PLATFORM INTEGRATION

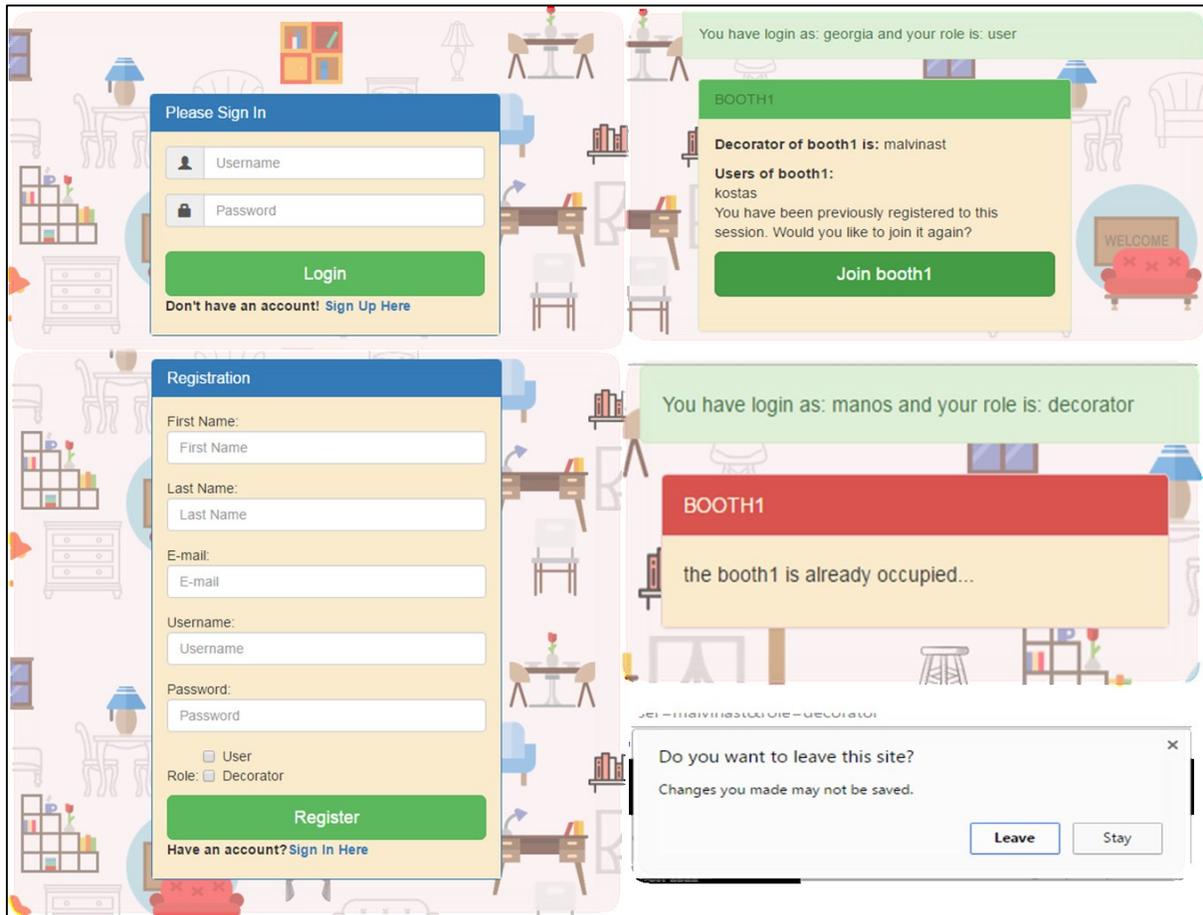
The implemented collaborative environment includes a X3DOM editor which takes advantage of WebRTC and Semantic Web standards for the real-time communication and interior design, respectively. Our application provides an integrated framework for all types of users (i.e content provider, designer, decorator, simple user) to communicate and directly exchange information.

User Management Service

On entering the application, user has the ability to log in with its credentials in order to “join” an available group and make use of the capabilities provided by the 3D collaborative environment. This environment not only supports the resizing, rescaling, relocation of physical objects and spaces, but it also comes with a semantic search engine for the inclusion of a desired object to the room space. Moreover, the implemented application makes feasible the communication of an unrestricted number of users in each active group, using either video call or chat messaging services. The available roles have been reduced to decorators and simple users, two basic components of the system that come with different functionalities in each session.

After the successful login to our system, users have the ability to join a “session” which is available at the current time. The notion of “Session” is synonym with a “Group” of users and becomes available when a decorator selects an unoccupied “session” from a list of rooms. On the other hand, if a “session” is occupied, then it is appeared in users’ dashboard. Every time a user or a decorator clicks on “join” button, he is automatically registered to the “session” and has the ability to carry out multi-user conferencing with video and audio call. Figure 3 shows an instance of a session, along with the relative notification message that informs user for previously joined sessions. Thanks to this retainment mechanism, our application is able to keep a history of the successfully connected users. So, if for any

1 reason someone logs out by mistake or due to a system fault, he is still able to join the same session again. However,
2 if a decorator logs out, then the session is instantly terminated.



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Figure 2. Instances of DECO user interface

Concerning the technical perspective of the user management service, we make use of a MySQL database which cooperates with Apache Tomcat and Node.js servers. Whenever a user attempts to login or register to DECO system, the corresponding servlets are called and run within Apache Tomcat server. The whole process of registration and authentication is based on servlet methods which are written in Java language and communicate with our database. The application reads the values from login and registration forms with JavaScript functions and calls the related servlets with the assistance of an AJAX engine. In this way, our system successfully updates specific only parts of the web page without reloading the entire page. On the other hand, the logout feature of the “session” takes place with MySQL module from the Node.js server. This is the best technique for notifying application’s users that the decorator of the specific “session” has left and this “session” is about to close.

Content Management Service

For the successful querying of the ontology, the system involves the population of the knowledge base with room spaces. Content providers or Designers, may use the web-based interface to assign individuals to classes and define their properties. The system, after that, takes the form of a questionnaire which is based on the stored ontology, using Jena and SDB. The application has been developed with the assistance of Apache Jena framework, taking advantage of its various integrated APIs for the manipulation of DECO ontology. The whole process of room annotation is exclusively done from this framework, while the presentation and user interaction is assisted by various technologies like Java Servlets, JSP, JavaScript and CSS, allowing in that way the on-the-fly manipulation of the ontology from the user.

Users are then asked by the decorator a number of questions regarding various parameters of the room. Their choices are sent to the corresponding servlet as a single SPARQL query which is processed by the SPARQL API of Jena Model Interface. After that, a connection to MySQL database is established and the query is executed against all the existing room spaces in MySQL database. Its results are sent back to the decorator as potential decoration solutions matching the needs of customers. At this point, decorator and user have the ability to visualize the room space chosen by the decorator in 3D format. Our aim was the enhancement of the online interior design module with choices drawn from the fusion of semantic ontologies and Web3D graphics.

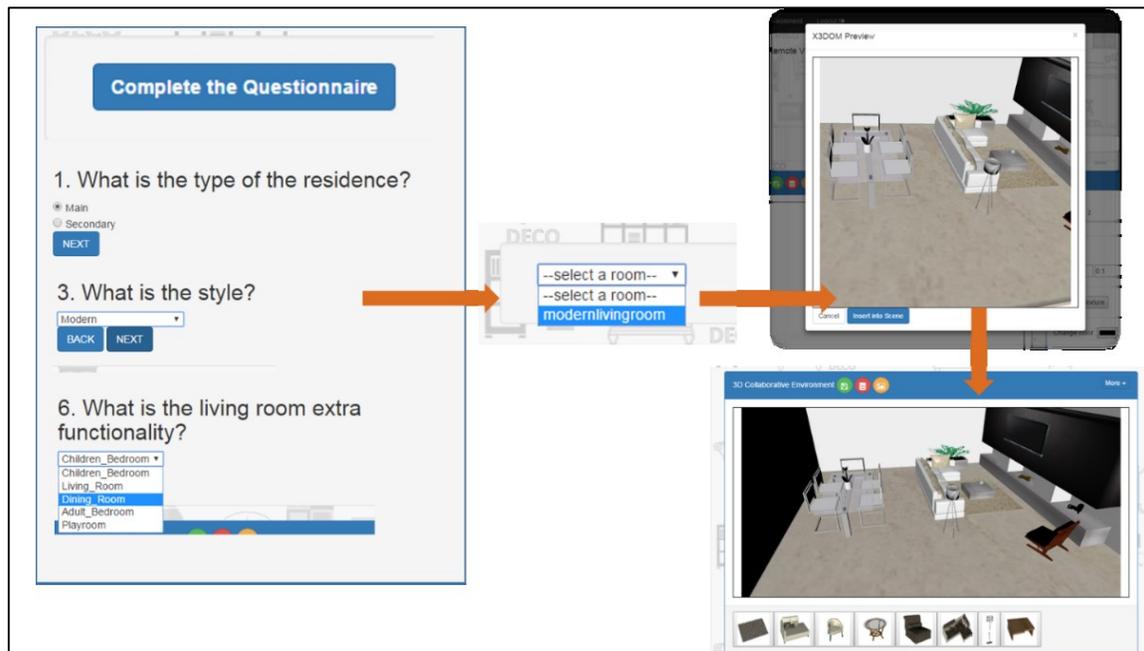


Figure 3. Questionnaire and pop-up window for 3D representation

Collaborative Management Service

As mention in Section 4.1 we have two available roles with the following functionalities:

<i>Functionalities</i>	<i>Decorator</i>	<i>Simple User (Customer)</i>
<i>Start a session</i>		
<i>Join a session</i>		
<i>Show video from all connected users</i>		
<i>Chat with all connected users</i>		
<i>Complete a questionnaire</i>		
<i>Preview decoration choices</i>		
<i>Insert the selected choice in 3D representation</i>		
<i>Adding recommended items from a list</i>		
<i>Upload an x3d file inside the 3D scene</i>		
<i>Move items around the 3D scene</i>		
<i>Change 3D items' color/texture</i>		
<i>Scale/Rotate 3D items</i>		
<i>Save the 3D scene in x3d format</i>		
<i>Take screenshot from 3D scene</i>		
<i>Close a session</i>		

Table 2. Fuctionalities of DECO application

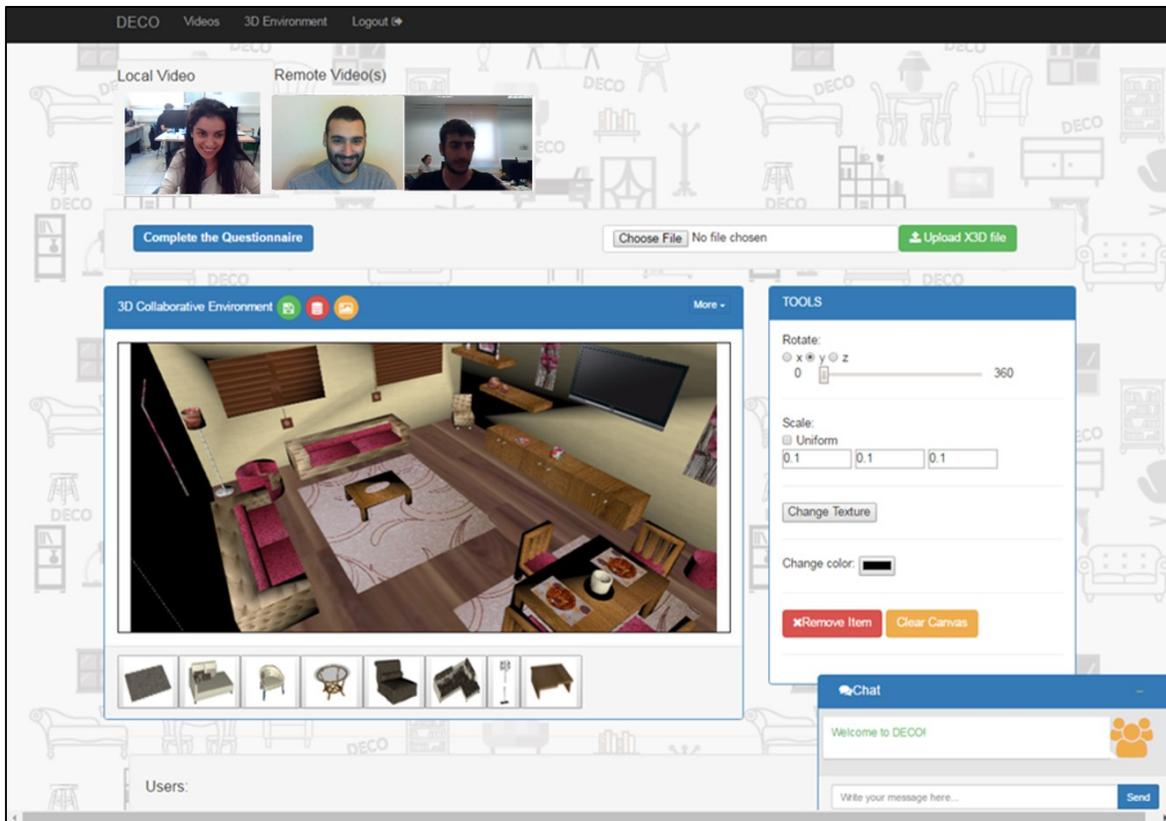


Figure 4. DECO application layout

Design Manager

In order to establish our collaborative design manager, we developed a 3D modeling environment with web-based communication capabilities. Users of the same “session” are working together on their corresponding web pages, sharing the same 3D scene and having the ability to add, remove, change position, color or choose the material of the 3D models of a room space. All connected users have the ability to see each other’s actions in real-time with the assistance of an MCU server. Our system can be proved a quite useful tool for non-professional customers and simple users.

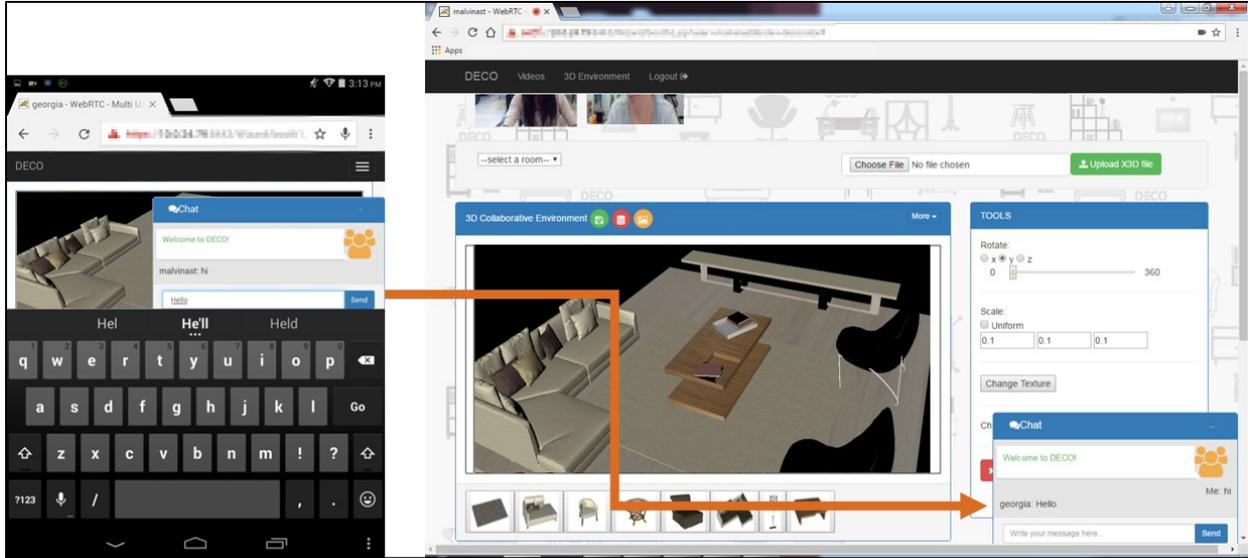


Figure 5. DECO Multi-user chat module. Left: tablet view, Right: desktop view

Our application extends commonly used real-time communication capabilities with the addition of a 3D representation format and the provision of extra functionalities that are found on X3DOM framework, like the real time modification of a room space. It is worthwhile to mention that the 3D representation takes place after the execution of semantic queries upon the stored ontologies and the deduction of the best fitting room to the decorator of the session.

Concerning the technical aspects of the aforementioned implementation, we have written our own MCU server in JavaScript language, allowing a wide range of devices (laptop with any operating system, smartphones, tablets with internet connection, etc.) to take advantage of our web application. The application ensures data integrity through a secure channel of communication via HTTPS protocol and guarantees the connectivity under different networks with the collaboration of a STUN server. The whole application is running under Apache Tomcat Server in cooperation with Node.js server and socket.io module for the real-time communication part of our application. For this reason, we have merged Apache Tomcat that runs Java based applications, with Node.js server that runs JavaScript based applications. Below, we explain how the server manages the messages of a user and how the rest of users are notified. As regards as the color picker example (Steiakaki, Kontakis, & Malamos, 2016), the user first selects a 3D item from an X3D scene, afterwards he clicks on the color button from the relative menu, and finally he chooses the desired color from the popped up color picker. This selection automatically notifies all other connected users of the same “session” about these changes in their X3D scene. In the same way, we are able to change the texture, size, position and viewpoints of the corresponding X3DOM scene. Technically, a message is emitted from this user to the Node.js server and socket.io event. The server after this broadcasts the received data to the rest of users, using the “emit” function of

1 the socket.io in order to achieve real-time communication. The following line is encoded in JSON format and is used
2 to notify the server that one of the users has changed the item with a specific id and color.

```
3 socket.emit('changeColor', {'type': 'changeColor', 'object':  
4 lastSelectedObject.getAttribute("id"), 'color': newCol});
```

5 *Table 3. Emit function example of the socket.io*

6 After that, server broadcasts the message to all connected users who received the JSON data and updates their 3D
7 scenes and specifically only the 3D item with the new color.

```
8 socket.on('changeColor', function (data) {  
9   var selObj = document.getElementById(data.object);  
10  for (child in selObj.childNodes) {  
11    if (x3dom.isa(selObj.childNodes[child]._x3domNode,  
12      x3dom.nodeTypeTypes.Appearance)) {  
13      selObj.childNodes[child]._x3domNode._cf.material.node  
14        ._xmlNode.setAttribute('diffuseColor', data.color);  
15      x3dom.reload();  
16    }  
17  }  
18 });
```

9 *Table 4. Listening of 'changeColor' event from clients*

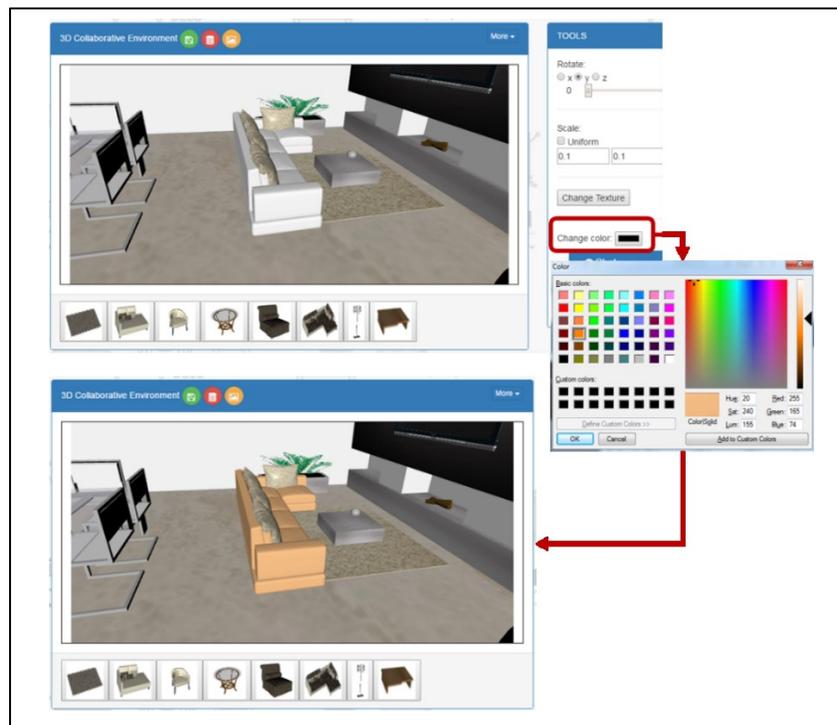


Figure 6. Changing the color of an item in X3DOM scene

1 Additionally, our application provides extra functionalities to its users, allowing them to insert other 3D items -which
2 are carefully proposed from an ontology- or to delete those items from the scene. The decorator has also the ability to
3 upload an X3D model (see Table 2 for more information).

5 Multi-Conferencing Manager

6 We have created several functions to initiate the signaling process with the creation of a new
7 RTCPeerConnection object for each new user who signs in. We keep a list of all connected peers and we manage the
8 action that the server must be done according to the method that every connected client call. Our MCU server detects
9 and manages the events for offer, answer and ice candidate, as we show in the Table 5.

```
10
var createUser = function(socket) {
  var objOfUser = {'socket': socket};
  //client sending offer
  objOfUser.socket.on('userOffer', receivedOffer.bind(objOfUser));
  //receiving an answer
  objOfUser.socket.on('userAnswer', receivedAnswer.bind(objOfUser));
  // listen for ice candidates
  objOfUser.socket.on('userIce', receivedIce.bind(objOfUser));

  function receivedOffer(data){...}

  function receivedAnswer(data){
    var userId = data.userId;
    data.userId = this.getUserId();
    if(connectingUsers[userId]){
      connectingUsers[userId].socket.emit('sendsAnswer', data);
    }
  }

  function receivedIce(data){...}
  ...
  // Return an instance of the createUser
  return objOfUser;
};
```

11 *Table 5. MCU code for managing events for multi-user conferencing*

12
13 On the other side, clients have the following code for the managing of the events

```
14
var objOfUser = {socket: socket};
// listen for server requesting offer
objOfUser.socket.on('requestsOffer', returnOffer);
// detect receiving an offer from server
objOfUser.socket.on('sendsOffer', returnAnswer);
// receive answer for server
objOfUser.socket.on('sendsAnswer', receiveAnswer);
// listen for ice candidates
```

```

objOfUser.socket.on('sendsIce', receiveIce);

// Receive offer request and return an offer
function returnOffer(data) {
// create RTCPeerConnection
createRTCPeer(function(rtcPeerConnection) {
initializeIce(rtcPeerConnection, data);
connectingUsers[data.userId] = rtcPeerConnection;
// create offer and send to server
rtcPeerConnection.createOffer(
function(offerResponse) {
data.offer = offerResponse;
rtcPeerConnection.setLocalDescription(offerResponse,
function() {
socket.emit('userOffer', data);
});
},
function() {
console.log("failure");
},
{
optional: [],
mandatory: {
OfferToReceiveAudio: true,
OfferToReceiveVideo: true
}
});
}, false);
function returnAnswer(data) {...}

function receiveAnswer(data) {...}

function receiveIce(data) {...}

...

```

Table 6. Clients code for managing the events for multi-user conferencing

1
2
3 To be more specific, when a user accesses the web page the CreateUser function is called and a group list
4 with connected users are generated with an RTCPeerConnection for this user. Then a message from this user is send
5 to the MCU server with the IceCandidates. At this point, the server requests an offer from the specified user and the
6 user responds with the createOffer function and his LocalDescription. When the server receives the offer, it emits the
7 data to the rest of connected users of this group. After this, the user responds with the createAnswer function of the
8 WebRTC to the MCU server, and finally the server emits a message with all answers to the remote users. Finally,
9 remote users call the SetRemoteDescription function to present the others' remote streams to their webpages. For the
10 connection under different networks, we use a list of free stun servers.
11

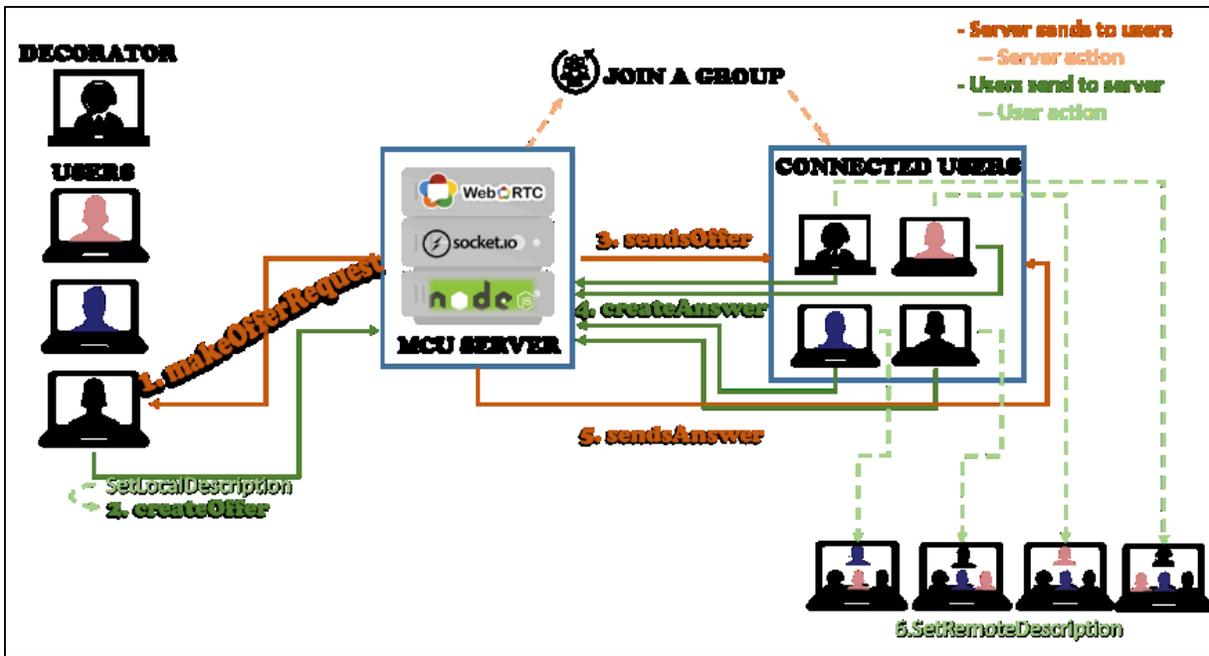


Figure 7. Process for multi-user conferencing using our MCU

5. EXPERIMENTAL RESULTS

An experimental environment was also set up in order to assess our ontology's degree of integration on interior design domain. For the purposes of this evaluation, 60 images depicting real-world room spaces were randomly selected from various sources available at the Web. This data sample was then equally distributed to 10 undergraduate students of the Department of Informatics Engineering of Technological Educational Institute of Crete, in order to define and populate the appropriate OWL ontology through our web-based framework. Each image corresponds to a distinct interior space that supplements such an ontology with its relative semantic concepts. These concepts come in the form of the qualitative and quantitative properties described in (Kontakis, Steiakaki, Kapetanakis, & Malamos, 2014), which are supplied from furniture, appliances, textiles, and other decorative accessories found on the specific room space. At the same time, each user reported any deficiencies or misconceptions met during the stage of annotation, concerning the input of new individuals to the predefined classes, the number and type of relationships between each individual, and finally rating the overall usability and reliability of our ontology. Their experimental evaluation was further processed in order to estimate the average user satisfaction in each basic element of the authored OWL-DL ontology. All results were gathered and are being presented in the following table.

<i>Question</i>	<i>Bedroom</i>		<i>Living Room</i>	
	Yes		Yes	
<i>Have you any deficiencies to the creation of new individuals to the predefined classes?</i>	Yes	15/60	Yes	5/60
	No	45/60	No	55/60
<i>Has our ontology enough (datatype) properties to describe the depicted room space?</i>	Yes	41/60	Yes	50/60
	No	19/60	No	10/60
<i>Is it easy to create statements with individuals of other classes (e.g. color, material, etc.)? object properties</i>	Yes	45/60	Yes	52/60
	No	15/60	No	8/60

Table 7. Questions & Answers ratio for ontology elements

<i>Characteristics</i>	<i>Rate (1 to 5 stars)</i>
Efficiency (Time behavior)	★★★★
Usability	★★★★★
Suitability with interior design concepts	★★★★★
Satisfaction from our application	★★★★

Table 8. Rating scores for abstract characteristics

6. CONCLUSION

We have presented an online collaborative framework that successfully integrates Semantic Web technologies and real-time communication capabilities under the same roof. At first, a comprehensible ontological editor was used to populate OWL-DL ontologies with the physical objects and abstract features depicted in a room space image. The overall annotation procedure was further enriched with the addition of a rule-based system for the provision of a

1 deductive reasoning mechanism to the end-users of the application. Such users are able to perform live video calls and
2 text messaging services with specific decorators through a utilitarian 3D environment. This media streaming takes
3 place with the assistance of WebRTC protocol's APIs and a custom made MCU server for the bridging of multipoint
4 conferencing users. The decorator plays the role of the coordinator and fills out a questionnaire according to user's
5 desires about an interior space. The questionnaire is based on SPARQL queries that ultimately return a single only
6 room from a database of ontologies, in order to display it in all participants as a common X3DOM scene. The 3D
7 objects included in this virtual world can be freely relocated, scaled and rotated, while a basic interaction and transition
8 with abstract concepts -like the color and texture of an object- is also feasible by all users. Lastly, a series of
9 experimental results upon the decorative accuracy of the authored ontology showed that it can sufficiently annotate
10 living rooms and bedrooms. Potential areas of application vary from simple online e-shops for the interior design
11 domain, to advanced AI systems that integrate automated reasoning solutions for research and commercial uses.

12

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