www.cadanda.com
Computer-Aided Design AND APPLICATIONS

A Web-based Platform to Support Contract Furniture Design

Maura Mengoni[1], Margherita Peruzzini[2], Roberto Raffaeli[3] and Damiano Raponi[4]

[1]Polytechnic University of Marche, m.mengoni@univpm.it
[2]Polytechnic University of Marche, m.peruzzini@univpm.it
[3]Polytechnic University of Marche, r.raffaeli@univpm.it
[4]Polytechnic University of Marche, d.raponi@univpm.it

ABSTRACT

Contract furniture design is the process of creating finished commodities for hospitality, retail, store, office, restaurants, etc. According to the process stage, numerous stakeholders with different skills, abilities, background and interests are involved in the development of products and services. The management of these temporary networks is complex and requires proper computer-supported cooperative work platforms able to achieve coherent design solutions. The paper explores contract furniture design challenges and requirements to define a technological platform to support companies in market analysis and penetration, product configuration and team working. System architecture and its main software modules are described in detail and preliminary implementation results shown.

Keywords: web enabled design, collaborative product development, virtual engineering.

1. INTRODUCTION

Contract market is a transversal business in the world of furniture, involving different types of products, from upholstered furniture to bedrooms, from seating to lamps, from office to bathrooms till outdoor furniture. It represents an increasingly important segment for furniture industry. Involved stakeholders are arranged into complex inter and intra temporary firm networks in which different interests, competences, abilities are brought to bear on products [8]. Contract furniture design involves interaction between actors situated at a number of sites along a commodity chain or network, including manufacturers, their suppliers, retailers, designers, consumers and marketers. The result of the network labor is the creation of a finished commodity for hospitality, which includes residences, tourist villages and hotels, for offices, retails, restaurants, marine, etc.

In this context, design cannot be seen as an isolated sphere of creativity, but it emerges from a wider field of relationships and knowledge of the entire network. Literature overview points out the multi-dimensional, multidisciplinary and multi-scale nature of contract furniture processes, services and products [11] and identifies the inner characteristics of furniture-dedicated products that are high-level customization according to the architectural space, the designer taste and style and the socio-cultural context, strong brand image, low manufacturing cost, eco-sustainability, high product durability and reliability, respect of international standards and reduced lead times [1].

New information communication technologies and web-enabled platforms have the potential to dramatically change furniture design, manufacturing and marketing [10]. These technologies are encouraging globalization, internationalization, cooperation, knowledge formalization and exchange. According to the process stage they can be classified into e-commerce solutions and computer-supported collaborative work applications (CSCW). The effectiveness of teamwork and the critical need for communication in the context of contract furniture push the present research toward the development of CAD-based and web-enabled platform capable of supporting the different phases of furniture design.

There have been many research efforts on enabling technologies or infrastructure to assist product designers in the computer-supported collaborative design environment [7], but none address contract furniture challenges. Some of them aim to help designers to collaborate with manufacturers by sharing product information and others to manage conflicts and support negotiation. Most promising

Taylor & Francis
Taylor & Francis Group

CSCW platforms provide a shared and distributed workspace where designers and manufacturers can access a product model, often in STEP standard, representing design information at several levels of granularity and check the status of their assigned tasks [13]. The functionalities of available platforms vary from data visualization to 3D model representation, real-time rendering, product model mark-up, audio-video communication support, and Web 2.0 services [6]. The review of CSCW applications highlights a lack of solutions dedicated to contract furniture able to simultaneously support information exchange along the whole contract furniture life cycle, temporary network reconfiguration according to the development stage and the involved stakeholders, customization of selected products and setting environment, the management of multiple and conflicting design constraints and process requirements, the creation of the whole furnishing Bill-of-Materials (BOM) and the distribution of product specifications to each supplier.

The research work aims to improve contract furniture design by developing a web-enabled solution capable to satisfy the need of the above-described network whose actors range from customers to manufacturers. This objective is part of a long-term research project, funded by the Italian Minster of Economic Development within Industria 2015 programs. Its final goal is the creation of a platform integrating e-marketing intelligence functionalities with online furnishing configuration and co-design tools based on virtual prototyping techniques and their experimentation on new hospitality concepts, developed for international luxury markets.

The first stage for the project goal achievement is the development of a platform supporting the following main functionalities: online product configuration and 3D visualization of the custom solution, selection of the personalized items and their integration into the 3D architectural environment taking into account all design constraints, creation of the BOM and identification of products to be co-designed to satisfy the designer specific needs and finally management of the contract project, design and development tasks, information flow.

The present work describes the adopted approach for the definition of the system architecture and the preliminary implementation results (i.e. integrated COTS components, programming platform and language, integrated commercial tools, dedicated plug-ins). It is structured as follows. Section 2 provides a review of state of art of supporting tools for contract furniture with the aim to classify them and identify main weaknesses. Section 3 reports the main steps of the approach to benchmark available tools and select functionalities to develop in the proposed platform. Approach application is illustrated in Section 4 that set the basis for the web-based platform implementation. The architecture, main software modules and adopted programming languages are described in detail in the last section.

2. SUPPORTING TOOLS FOR CONTRACT FURNITURE DESIGN

Contract furniture is defined as a particular form of mass customization referring to specific Business-to-Business (B2B) requirements such as high product durability, service reliability, personalization, respect of international technical and functional standards, etc. [4]. It requires an high level of collaboration and synchronization: from the integration of single "pieces of work" which are individually developed (i.e. tasks, decisions, analysis) to the combination of different working actions due to the actors' working way (i.e. work at computers, talk to other designers or specialists, solve problems by acting on the product models). Power and Jansson [11] point out the multi-dimensional, multidisciplinary and multi-scale nature of contract furniture processes, services and products. They outline the characteristics of contract design identifying it as strongly participatory. Participatory Design (PD) is an acknowledged approach to support effective design collaboration. It aims to involve users as much as possible so that they can influence design itself, integrate knowledge and expertise from numerous disciplines, and be highly iterative [12]. PD can realize the integration of all involved actors and organizations in order to achieve a common goal and the coordination of material, information and financial flows during shared project deployment.

The spread of virtual environments and opportunities of web-enabled solutions have lead to new ways for designers to collaborate and new "places" for designers to participatory design. There is a growing interest toward the creation of new paradigms of web-based Collaborative Product Development (CPD) driven by increased outsourcing, competition and pressure to reduce development time.

Recently, there have been some attempts to create contract furniture-oriented web communities and interest groups involving manufacturers, architects and product designers [2,14,15]. The provided advantages of idea and information sharing confront with the difficulties of these platforms to manage technical data, schedule tasks and activities, support product configuration and modifications. Furthermore, they do not offer any shared tool to support design and to provide different levels of abstraction to make actors actively participate. As a result, in contract furniture collaboration is still limited, human interaction is fairly superficial and design process is disorganized.

Computer-supported collaborative design is a wide area of research focused on the development of web-based methodologies and prototype systems for Computer-Supporting Cooperative Work (CSCW). Most solutions are developed to enable data sharing,

process/project management and conflict resolution, remote cooperation, and synchronous collaboration at different stages of product design [7]. Extensive researches are reported in literature on collaborative Computer-Aided Design (CAD) addressing issues such as co-design, collaborative modelling, assembly-based representation, web-based visualization and 3D streaming over networks [5,9]. Some are based on client-server models, others on peer-to-peer network.

Despite numerous research efforts on enabling technologies or infrastructure to assist product designers in the CSCW environment [7], none address contract furniture challenges. Both in research and in industrial applications, the market lacks integrated, flexible and cost-effective solutions to support contract furniture design. Most researches provide either web-based environments for CPD or shared CAD systems for product modeling and review. None solution offers an integrated environment for collaborative data management, product modeling, review and decision-making. The most promising ones provide a shared and distributed workspace where designers and manufacturers can access a product model, often in STEP standard, representing design information at several levels of granularity and check the status of their assigned tasks [13]. On the other hand, commercial solutions are large-scale, expensive, not easily customizable and scarcely fit with the needs of small and medium sized enterprises that are generally involved in contract furniture chains.

In spite of a lack of contract furniture-oriented applications, a preliminary review of potential supporting technologies leads to the following classification:

(1) Dedicated CAD-based configuration systems: they refer to commercial configuration systems or open-source platforms (e.g. Metron (http://tesysoftware.net), 3CAD evolution (http://www.3cadevolution.it), Mobilia (http://mobiliasoft.com)). They are client applications dedicated to the furniture sector. They usually have tools to handle CAD models and configure them and the surrounding environment, and to generate the complete BOM. They adopt a single company perspective, so they cannot support collaboration and co-design within an extended network;
(2) General-purpose 3D modelling systems: they are 3D modelling tools that can be adopted mainly for architectural design (e.g. Google Sketch-up and Sketch-up PRO (http://www.sketchup.com/intl/en)). They are general-purpose and easy-to-use, so they can be easily adopted to create an environment and populate it with product models. They are client-based but also support model sharing through the web. However, rendering quality is low and most design tasks are not fully supported;
(3) Web-based 3D configuration systems: they are free or open-source platforms for interior design, which allow a 2D-3D environment to be created where furniture items can be positioned and rendered (e.g. Sweethome3D (http://www.sweethome3d.com), DomusPlanner (http://www.domusplanner.com)). They are easy-to-use, intuitive and low cost. They allow easily data sharing through the web. However, they do not support technical product configuration so that they are suitable for final customers but not for architects and/or manufacturers;
(4) Co-design tools: they allow to visualize 3D models in a shared modality by involving multiple users, to navigate the space also by walkthrough, to mark-up file, to chat during designing and keep track of the comments (e.g. Oracle Autovue (http://www.oracle.com/us/products/applications/autoVue), Actify SpinFire (http://www.actify.com/products/spinfire-cad-solution-system), Autodesk Streamline (http://www.autodesk.it/streamline)). They are low-cost and multi-systems. Image quality is low, they do not support real time modelling;
(5) CAD-based plug-in for configuration management: they consist of plug-in applications developed for interfacing with specific CAD commercial systems (e.g. SolidEdge, SolidWorks, PRO/E, Catia) to manage product variables and assembly configuration, create relationships among product features and dimensions, and handle modular assemblies. They allow design task to be carried out. Rendering quality is poor and data sharing is not available. They are not easy to use for non-expert users.

An extensive review of the above mentioned platforms is performed and shown in Tab. 1. Each class is analysed according to the supported functionalities, programming language, system requirements (e.g. graphic board, operating system, bandwidth).

The investigation of available technologies strengths and weaknesses highlights that the main challenge for contract design is the creation of a suitable system able to combine the management of product technical features and variants like a CAD-based plug-in, the management of the whole environment configuration and configuration rules like a CAD-based configuration system, the real-time collaboration typical of co-design tools, the availability and low-cost typical of web-based 3D configuration systems, and high-quality aesthetic rendering that can be obtained by IT development frameworks and platforms (e.g. .NET (http://www.microsoft.com/net), X3D (http://www.web3d.org/x3d), OpenGL (http://www.opengl.org), JReality (http://www3.math.tu-berlin.de/jreality)).

	CAD-based system for 3D modelling and product configuration			Web-enabled platform not integrated with CAD	Open-source platforms		*Other*
	Google SketchUp Free	Google SketchUp Pro	Metron	XVR Studio (Percro Center, Pisa)	Sweet Home 3D	JReality (based on JAVA 3D)	*Others*
Client-based	Desktop app	Desktop app	Desktop app	Web-based technology	Desktop and internet-based	-	...
Server like	Data sharing	Data sharing	Terminal server	Data sharing	Web server	-	...
Programming language	Ruby	Ruby	No	Dedicated script for low-level OpenGL programming. Interfacing with HTML, Javascript or VBScript	Java	Java	...
Network infrastructure for distributed data management	None for software application use, every type for DB access	None for software application use, every type for DB access	None for software application use, every type for DB access	TCP and UDP management	Large bandwidth	No bandwidth	...
System requirements (graphic board, operating system, bandwidth)	OS: Windows XP, Vista, Mac OS X.; CPU 2 GHz, min 2GB RAM; Board: 3D class supporting OpenGL 1.5	OS: Windows XP, Vista, Mac OS X.; CPU 2 GHz, min 2GB RAM; Board: 3D class supporting OpenGL 1.5	LAN for DB Access	Processor Pentium 3 800 MHz, SO: Windows 98/Me, 2000/XP, Vista; RAM: 128 MB; Graphic board: compatible with OpenGL; Audio board: 16 bit DirectX. Browser: Internet Explorer	All OS with JVM. CPU 400 MHz, 256 MB RAM	All OS with JVM. CPU 2 GHz, min 2 GB RAM, support OpenGL 1.5	...
Plug-in development	Yes	Yes	No	Yes	Yes	Yes	...
GUI customization	No	No	No	Yes	Yes	Yes	...
Geometric model import	Yes	Yes	Yes	Yes	Yes	No	...
Other requirements	...	...	...	...	...	...	...

Tab. 1: Example of systems' overview.

Computer-Aided Design & Applications, 11(5), 2014, 533–543, http://dx.doi.org/10.1080/16864360.2014.902684

3. THE ADOPTED APPROACH FOR PLATFORM DEFINITION

In order to define a new system able to overcome the actual limitations of co-design tools for contract furniture industry and efficiently support participatory teamwork during the design stages, a structured methodology is defined. It supports the definition of proper system architecture according to specific application requirements. It allows the system requirements to be elicited, available technologies to be benchmarked and the main architecture modules identified. The proposed method can be summarized into 5 main steps:

(1) Analysis of the AS-IS contract design process: the design process is investigated by questionnaires and direct interviews involving the main process actors belonging to complementary companies to highlight the main criticalities of the actual process. The AS-IS process is modeled by adopting mind maps. Analysis concerns the process activities development and tasks, the collaboration issues, input and output data typology and management, design offer features and variability. All feedbacks are collected and the most frequently responses are considered. Investigation is carried out by experts from Academia and industry;
(2) Elaboration of the TO-BE interaction model: in order to overcome the AS-IS criticalities, a TO-BE process model is conceived. It considers the perspective of all actors involved and complies with user requirements. After than, an interaction model is defined by comprehending a supporting system and use scenarios are depicted to evaluate the impact on final users;
(3) Elicitation of users requirements: a set of expected user requirements representing their needs is elicited. Each requirement is provided by a weight expressing its relevance according to a 5-point scale, which derives from both experts and process actors feedback on the analysis of AS-IS and TO-BE processes;
(4) Benchmarking of the supporting technologies: the most suitable technologies are selected and analyzed according to their main capabilities (technology classification). Then, the different technology classes are correlated to user requirements by adopting Quality Functional Deployment (QFD) methods [3]. A correlation matrix is used to evaluate how systems are able to satisfy each requirement. It allows each requirement to be weighted according to its relevance and a global evaluation achieved. In this way the most proper technologies can be identified. Benchmarking exploits a correlation matrix able to combine system capabilities and requirements, and to weight them according to the requirements' relevance. For each analyzed technology j, a total evaluation value (TEj) is calculated by equation (1):

$$TE_j = \sum_{i=1}^{n} Ai * Bi \tag{1}$$

where Ai is the weight of the *i-esimo* requirement, Bi is the assessment of the j technology for the *i-esimo* requirement, and n is the number of considered requirements.
(5) Definition of the platform architecture: the selected technologies are integrated into a unique system platform and the system architecture is defined. In particular, the user interfaces and the platform modules are stated, and the input/output data flows are outlined to drive the following system development.

4. THE DESIGNET CASE STUDY

The methodology has been applied to support a cluster of companies aiming to operate in the contract furniture sector (mainly hospitality and retail). The project is called DesigNET (http://www.designet-italy.it). It is an Italian project promoting innovation and Made in Italy lifestyle and involves 17 companies that are product manufactures, suppliers and design studios. They vary in size, organization and core business. It started in 2011 and lasts three years. The Italian Ministry of Economic Development funds it. The project goal is to realize a multi-disciplinary organization thanks to an innovative supporting technological platform able to:

- provide a showcase of the innovation and competencies of the DesigNET companies,
- configure the designed space as a whole and the single products in details to meet commitment expectations and companies' capabilities,
- realize an effective collaboration to co-design custom products, personalized variants or new integrated solutions.

The following sub-sections describe the results of methodology application to achieve a complete definition of the DesigNET platform for contract furniture design, whose architecture is described in chapter 5.

4.1. Contract Furniture AS-IS Process

Questionnaires and interviews are submitted to a total number of 51 users, three for each involved company. Their judgements allow the main characteristics of contract furniture to be outlined and arranged according to the following aspects:

(1) *Process*. The arrangement of a contract cluster starts from a new project that is generally

proposed by a buyer, a general contractor or a designer/architect. These actors are generally responsible in the creation of the temporary network that increases in terms of participants' number during the project duration. In most cases the architect is assigned to identify the proper design solutions to be included in the furniture or those that need to be integrated and customized. He/she becomes the first interface between the buyer and the manufacturers/suppliers. The architect manages most design issues, whereas the general contractor or directly the buyer/owner supervise economic and temporal issues. Negotiation is time consuming and brings to iterative modifications until an agreement is achieved. Such negotiation is repeated for each furniture supplier. The identified key factors for the process success are: loyalty, reactivity and novelty. The manufacturer's guarantee of a solid partnership is fundamental to be firstly involved by designers/architects or general contractors (loyalty). Timeliness is decisive to win the competitive bid so that the company has to clearly define items features and typology from the earliest stages to enable the contractor to generate accurate and reliable estimates (reactivity). Finally, the offer has to be fresh and distinctive in order to differ from competitors (novelty). The main process criticalities are related to: the achievement of a mutual evaluation of both technical aspects and aesthetic impression of the overall furnishing, the realization of a shared understanding of the designed environment and the relationships among the single items (i.e. level of integration, compatibility, assemblability), the shared understanding of the buyer expectation to elaborate a satisfying proposal, the organization of process activities according to partners' roles and the synchronization of different companies' tasks to respect cost and time constraints;

(2) *Representation media*. The means of design representation vary according to the design stage and the teamwork composition: from abstract and unstructured representations during conceptual design (i.e. sketches, images, simplified digital models) to CAD-based representations and simulations during embodiment design (e.g. structural and thermal performance, kinematics, process simulation, ergonomics). The management of team structure and roles as well as data evolution, decision-making activities and knowledge formalization to preserve all generated information is imperative.

(3) *Team composition.* The required design network is definitely extended, temporary and changeable according to external factors (e.g. location, timing, costs, provided competences and items). The working team is multifaceted: it is made of company internal figures (i.e. marketing staff, engineers, stylists, top managers, CEO) and external ones such as the buyer and/or owner, external designers, general contractor, architects, commercial agents, installers, mediators, end-users. The involvement of end-users and owners leads to personalized solutions and to the creation of high-perceived quality products. Cooperation among companies, suppliers and partners allow resources and processes to be optimized and costs reduced.

(4) *Product and service features.* Furnishing is characterized by specific aesthetic and functional requirements depending on the needs of the target market, the country, customer profiles, contract typology (e.g. hotel, retail, store). In all cases the main characteristics to be pursued for the commodity are high level of personalization of the designed solutions, low cost, high product/environment quality perceived by the customers, high durability, respect of international technical-functional standards, impact of furniture in space perception and living quality. Personalization is much more than a simple product dimensions' variation, as it is extended to finishing, functions and technological features that are usually not expected in mass production. It is achieved by combining parameterization, configuration and feature innovation. All items must respect not only international standards but also specific country regulations concerning different aspects (e.g. ergonomics, security, safety) and different user profiles (e.g. children, teenagers, elderly people, disable people). The perceived quality of the commodity strongly depends on single product configuration and on their integration and mutual relationship in the environment. Thus, furnishing must respect a unique aesthetic style.

(5) *Effects of the agreement between all involved companies.* The term "contract" itself refers to the written agreement between the seller and buyer when the goods are bought. The presence of such a "contract" has four main consequences:
- the commitment is determined by several figures (mainly the owner, the general contractor, and the architect, but also partners or stakeholders can interfere);
- time constraints are established in advance and must be strictly respected (penalties are usually given for delays or inefficiencies);
- the negotiation phase is long and complex since the design of each single item

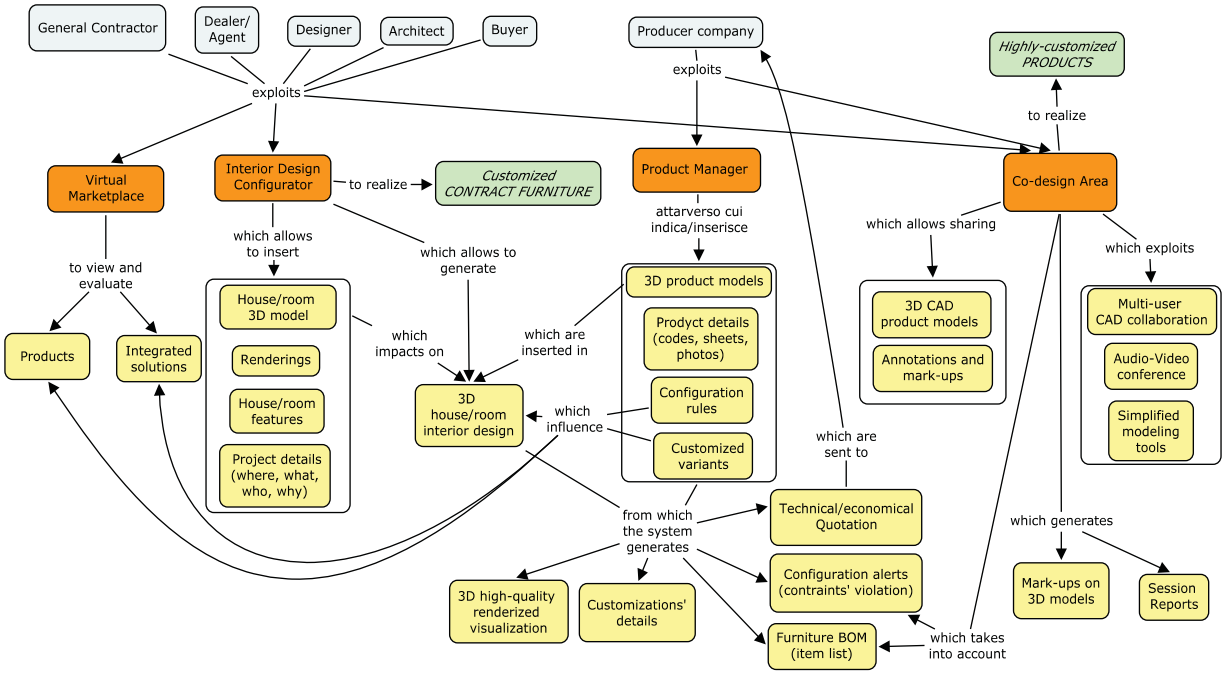

Fig. 1: The TO-BE process model.

is usually defined in relation to the other products or services; as a consequence cost budget is global and comprehends all the furniture;

- the goal is furnishing large spaces so that furnishing refers to numerous items (e.g. single products, room decoration, lighting) and the design project must be defined combining product and architectural features.
- A unique interface between the buyer and all involved stakeholders is necessary to realize a turnkey project covering all buyers' needs.

4.2. Contract Furniture TO-BE Model

The TO-BE process aims to overcome the AS-IS outlined weaknesses by proposing innovative use scenarios. Fig. 1 shows the conceived TO-BE interaction model. It represents how the process could be carried out once supported by new web-enabled supporting tools managing the above-described aspects of contract furniture.

In particular, it requires four main user interfaces:

- a web-based virtual marketplace promoting in an appealing way the products offered by different manufacturers that can be arranged into temporary clusters according to the user selections;
- a configuration tool able to support the 3D configuration of both products and architectural space according to predefined rules and design best practices;
- a management tool to make companies upload products and solutions into the catalogue, preset the product variants (e.g. colors, finishing, functions, features) and add technical documentation for contractors, designers, architects and end-users;
- a co-design area supporting real time and remote collaboration among multiple users, geographically dislocated.

4.3. User Requirements and Benchmark of Supporting Tools

Requirement elicitation has been achieved by combining the TO-BE interaction model with the expected functionalities of the user interfaces. Requirements are grouped into six categories as reported in Tab. 2. DesigNET cluster companies are involved both in requirements' improvement and weights assessment. For each company, two mangers, one coming from R&D department and one from the marketing one, are asked to express the importance that each requirement has for the company but also for the architects and designers he/she collaborates in contract furniture. In addition five external designers, that usually works in hospitality and retails, and two general contractors are involved in this assessment. Weights data are averaged on 40 total judges.

One or more tools for each of the five technology classes are selected and compared. They are: a Java web-based system (i.e. JReality), two HTML5 + WebGL Frameworks (i.e. X3D and C3DL) and two web-based configurators for interior design (i.e. Sweethome3D

CAT.	USER REQUIREMENT	Weight
Visualization	UR1. Real-time selection of the available product variants	4
	UR2. Virtual marketplace (web-based)	5
	UR3. Import of 2D model by .dwg/.dxf formats and creation of the related 3D model of the environment	4
	UR4. Indication of doors, windows and other remarkable points (e.g. drains, electrical connections)	3
	UR5. Import of 3D CAD models of furniture items (single products) by standard format (.stp)	4
	UR6. Wizard procedure to easily guide users in data input (cost budget, design features, desired functions)	5
	UR7. Inserting 3D product models into the environment by drag&drop	4
	UR8. Exploring both products and environments by walkthrough	4
Rendering	UR9. Realistic visual representations of 3D models of both single products and integrated solutions	5
	UR10. Real time rendering of the environment during configuration	3
	UR11. Export of the rendered 3D model of the global environment in a secure format (not editable)	4
	UR12. Export of the final 3d model for VR or AR applications	3
Modeling	UR13. Basic modeling tools (e.g. protrusions, holes, etc.)	3
	UR14. Basic measuring tools (e.g. distance, area, volume)	5
	UR15. Generation of thickness on 2D models	2
	UR16. Extraction of simple 2D geometry from 3D models (e.g. edges)	3
Rule Configuration	UR17. Dimensional rules and definition of acceptable ranges for distance, areas and volumes	5
	UR18. Basic interior design rules (e.g. acceptable distances) and best practices to support item positioning	4
	UR19. Management of product alternatives on the basis of design constraints and user's preference	3
	UR20. Modification of 3D product models after importing by stretching or resizing	2
	UR21. Reporting of cases in which standard products must be customized (by specifying the changes)	4
	UR22. Wizard procedure to guide the user's choice of the different product categories	4
Data Manag.	UR23. Automatic generation of the global environment BOM	5
	UR24. Correlation between product and technical data (e.g. photos, technical sheets, 2D drawing details)	4
	UR25. Notification to the user about price for standard product and for customization (by percentage)	4
	UR26. Notification to the company about new configuration integrating its own products	5
Collaboration	UR27. Real time collaboration between multiple users	5
	UR28. Remote visualization of 3D models	4
	UR29. High-quality rendering	2
	UR30. Audio-video communication	4
	UR31. Mark-up on 3D models (e.g. notes, comments, attachments)	5

Tab. 2: User requirements.

and DomusPlanner), two co- design tools (i.e. Autovue and Hops streaming), a CAD-based plug-in (i.e. SolidWorks eDrawing), and finally two general-purpose 3D modeling tools (i.e. Google Sketch-up and CoCreate OneSpace). In addition four SW development frameworks (i.e. .NET, ASP.NET, WebGL, OpenGL.) are assessed. Two experts, one from Academia and one from the largest company of the partnership (i.e. iGuzzini) evaluate each tool (j) assigning 0-3-9 values (Bi) for each user requirements (i). For each tool values are weighted according to the requirements' relevance (Ai) and then summed according to equation (1) to obtain a total evaluation. Tab. 2 shows the final evaluation for the case study, reporting the averaged values achieved for each requirement class. Highest values indicate those systems, which better satisfy contract design needs.

The most proper selected technologies for the DesigNET context of use result to be as follows:

- ASP.NET technology: it will adopted for developing the platform web applications as far as the

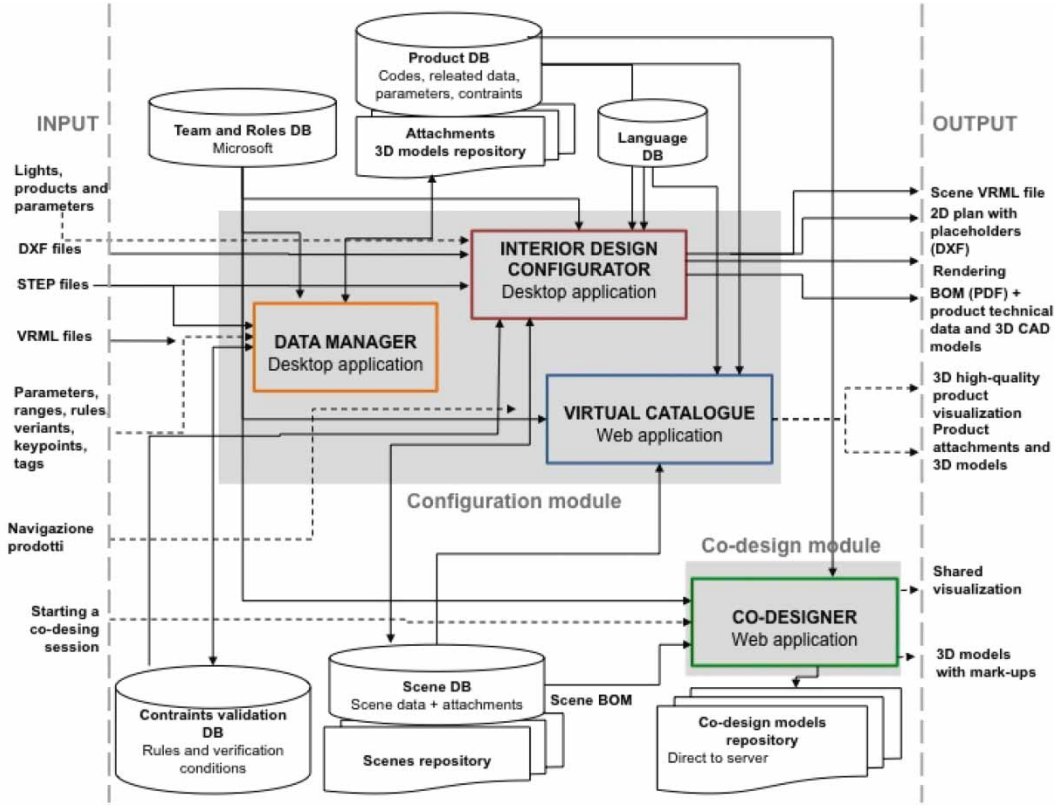

Fig. 2: Platform architecture and overall system design.

virtual catalogue and the configurator interfaces are concerned;

- OpenGL (Open Graphics Library): it will be used to realize the graphic engine and manage high-quality rendering inside the configurator;
- VB.NET framework: it will allow to develop the configurator engine in order to manage 2D and 3D geometries, product variants, configuration rules, constraints check, user roles and permission, databases, BOM creation and data exchange. It will be common to configurator and manager interfaces;
- WebGL platform: it will support programming the 3D web-based interactive interface of the virtual catalogue;
- Autovue Oracle platform: it will be integrated into the .NET framework to support real-time collaboration.

5. THE DESIGNET PLATFORM: SYSTEM ARCHITECTURE AND MAIN MODULES

The selected technologies need to be properly integrated to realize a unique system accessible by different user interfaces to support diverse viewpoints and guarantee different levels of abstraction. Indeed, it is imperative to provide at least four user interfaces with different functionalities and levels of usability because all involved stakeholders differ for their personal background (e.g. engineering, architectural, economics), purposes (e.g. technical, economical, product-centered, holistic, etc.) and needs (e.g. the interior architect has to configure the space, the designer to shape a new customized product, the contractor/buyer to find out the cheapest solution and have a global overview of the furniture offer and the manufacturer to create an offer based on user requests). The platform architecture is structured in two main modules whose access is provided by the different user interfaces. Main input and output data are defined and then organized into a unique system platform as shown in Fig. 2.

The configuration module aims to configure the desired space by choosing the most appropriate items to furnish the empty space. It has three main interfaces:

1. Virtual Catalogue: it is a web-based marketplace where the user can view a rich catalogue of products and integrated solutions proposed by manufacturing companies and evaluate all product variables by an high-quality 3D rendering, refreshing once a parameter changes (e.g. color, finishing, dimensions, accessories, performance). Each item is correlated with its technical documentation (e.g. 3D models, 2D drawings, manuals, data sheet). Such interface is barrier-free since it is on the web and has a public access throughout the most common

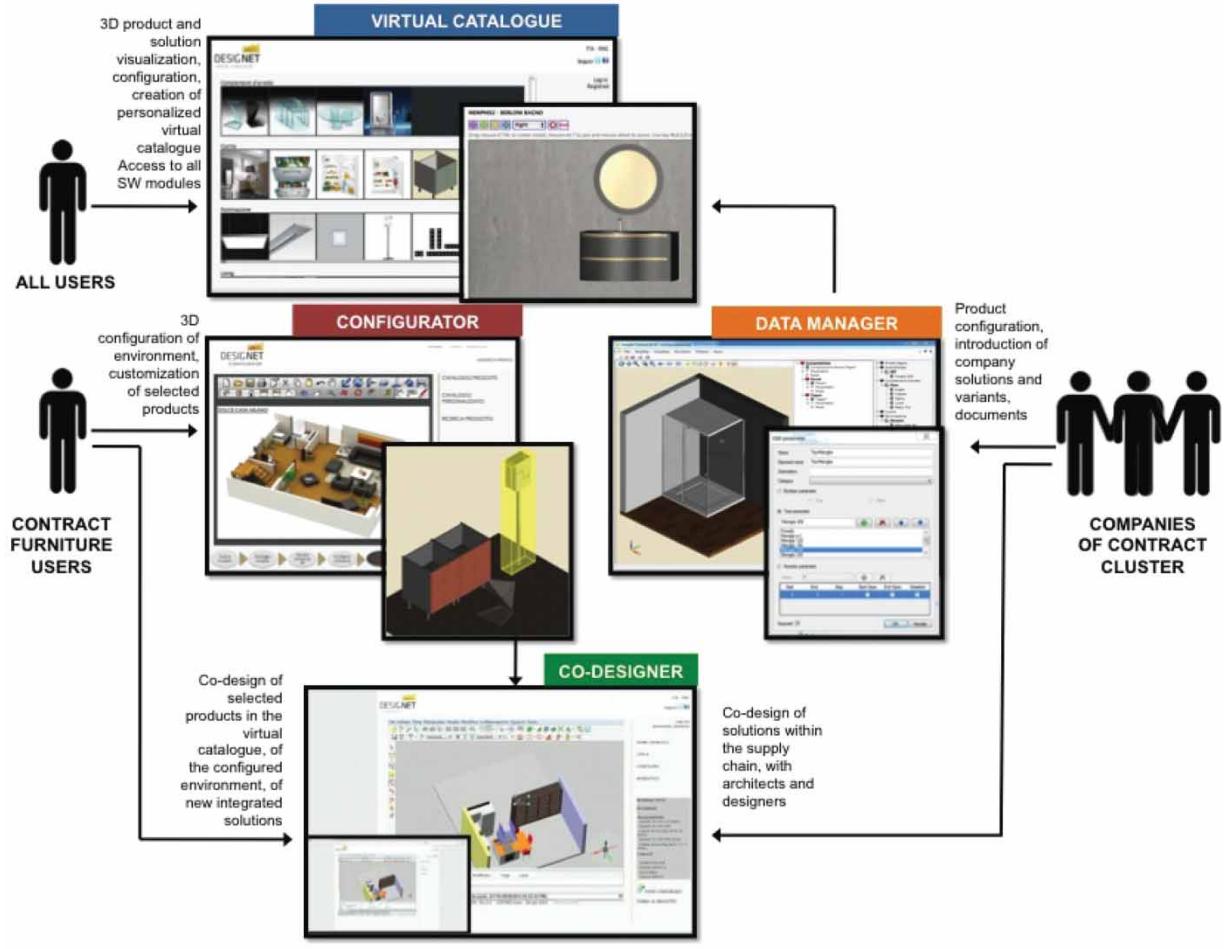

Fig. 3: The implemented modules.

Internet browsers. If the user needs to download special technical documentation, he/she has to login in or register as a new user. A software module allows the user identification, authentication and tracking to achieve a complete profile. The Virtual Catalogue is written in ASP.NET code to produce dynamic Web pages, applications and services and adopts WebGL libraries for rendering interactive 2D and 3D graphics of product models, scene and solutions within any compatible web browser without the use of custom plug-ins.

2. Interior Design Configurator: it is the configuration engine and allows the user to create a personal project, importing a 2D or 3D space model (e.g. hotel room, store space) and populate the empty space by selecting the catalogue items. It supports product configuration and positioning into the space by following the manufacturer's guidelines (e.g. a bookcase that requires to be attached to the wall) and respecting some technical constraints (e.g. the minimum empty surface of the wall and its minimum resistance) by exploiting a knowledge-based set of rules which explicit the relationships among products and the environment. It is a desktop-based application the user can download once logged into the DesigNET Virtual Catalogue. It is interfaced and synchronized with the Virtual Catalogue to keep the selected products and solutions ever updated. The Configurator is implemented on the VB.NET Framework adopting an object-oriented computer programming language and adopts WebGL libraries to realize 2D and 3D graphics.

3. Data Manager: it is a technical product manager that allows the manufacturer to upload and define their own products, all feasible variables and the possible ranges of parameters' modification. For each item the company has to provide a 3D model, indicate the product existing or customizable characteristics (e.g. materials, surface finishing), specify the optional accessories (e.g. handles typology), define the customizable features and their allowed range of variation (e.g. max-min length), add the installation constraints to be respected (e.g. maximum distance to the power socket of 30 cm) or the suggested configuration constraints (e.g. wall contact is required). Additional data can be further attached such as user manuals or product renderings. It is a complete desktop application developed in VB.NET framework and synchronized with all the system databases.

The co-design module supports the technical configuration and co-creation of customized products or integrated design solutions by a web-based collaborative space. Such a tool is fundamental when the existing products cannot satisfy a certain demand and a customized product is required or when the architect has to create a special solution for the configured space. It has one main interface that is called, *Co-designer*. It is the technical collaboration area offering a shared co-design space to support product configuration in a collaborative modality on the web. All actors involved in a specific project (i.e. designer, general contractor, R&D company staff, company commercial manager, supplier) can access a common area, share 3D models or office file and images, and contemporary interact by audio-video conferencing. Real time collaboration is fundamental to identify the necessary changes and to find out the best solution. The co-designer is implemented by integrating different COTS (Commercial Off The Shelf) tools with some ad-hoc applications and functionalities. The module framework consists of a portal server (Microsoft Office Sharepoint Server 2007) that runs Oracle Autovue to open different native formats and configured solutions, upload huge CAD assemblies retrieving all attributes, documents, annotations the different process stakeholders have introduced, analyze the shared model from a common viewpoint or from different perspectives according to the number of collaborative session participants, collaborating by adopting both audio and video modalities and exploiting Skype instant messaging functionalities. Fig. 3 shows the main implemented modules of the whole DesigNET platform.

6. CONCLUSION AND FUTURE WORK

The research addresses the main challenges in contract furniture design. It provides a structured approach to create a supporting web-based platform to manage 3D furnishing configuration and collaborative product development in the extended and temporary commodity network. The work illustrates the result of the benchmarking of contract furniture-oriented technologies and the preliminary developments of platform implementation.

REFERENCES

[1] Bullard, S. H.: Innovative and evaporate - Business concept innovation in the furniture industry in the age of information' Bulletin FP 228. Forest and Wildlife Research Center, Mississippi State University, Mississippi State, 2002.

[2] CDM: Contract Design Magazine, available at www.contractdesign.com , 2012.

[3] Cohen, L.: Quality Function Deployment, how to make QFD Work for You, Addison-Wesley, 1995.

[4] Fogliatto, F. S.; da Silveira, G. J. C.; Borenstein, D.: The mass customization decade: An updated review of the literature', Int. J. Production Economics, 138(1), 2012, 14–25.

[5] Fuh, I. Y. H.; Li, W. D.: Advances in collaborative CAD: the state of art, Computer Aided Design, 37 (5), 2005, 571–581.

[6] He, F.; Han, S.: A method and tool for human-human interaction and instant collaboration in CSCW-based CAD, Computer in Industry, 57 (8–9), 2006, 740–751

[7] Li, Y. L.; Shao, X. Y.; Li, P. G.; Liu, Q.: Design and Implementation of A Process-oriented Intelligent, Collaborative Product Design System, Computer in Industry, 53, 2004, 205–229.

[8] Maddaloni, S.; Volpe, A.: The World Hospitality Market, CSIL Milano–Furniture Industry Research, Available online: http://www.worldfurnitureonline.com, 2011.

[9] Mavrikios D.; Alexopoulos, K.,; Xanthakis, V.; Pappas, M.; Smparounis, K.; Chryssolouris, G.: A web-based platform for collaborative product design, review and evaluation, in Digital factory for Human-oriented Production Systems, Eds. Cannetta L., Redaelli C., Flores M., Springer Verlag London, 2012, 36–54.

[10] Moodley, S.: Global Market access in the Internet Era: South Africa's wood Furniture industry, Internet Research, 12(1), 2002, 31–42

[11] Power, D.; Jansson, J.: Cyclical cluster in global circuits: overlapping spaces in furniture trade fairs, Economic Geography, 84(4), 2008, 423–448.

[12] Preece, J.; Rogers, Y.; Sharp, H.: Interaction Design, Ed., Wiley, 2002.

[13] Sriram, R. D: Distributed and Integrated Collaborative Engineering Design, Sarven Publishers, Glenwood MD 21738, USA, 2002.

[14] WCD, Worldplace Contract Design, available at www.wcdllc.com (accessed on 2012-12-10).

[15] WFO, World Forniture Online, available at www.worldfurnitureonline.com (accessed on 2012-12-10).