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Toward an integrated platform to support contract furniture industry

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ABSTRACT
The paper presents an integrated technological framework, which aims to make a step forward in contract furniture design methods and supporting web-enabling applications. The implementing platform enables the extensible and temporary cluster of companies to manage the entire contract furniture process. The main contribution regards the integration of different software modules into an overall system that exploits E-marketing Intelligence applications, 3D web-based tools and Augmented Reality techniques. Different user interfaces are implemented to accomplish the involved stakeholders needs and furniture development goals.

KEYWORDS
Web-enabled design; E-marketing; Collaborative Product Development

1. Introduction

The current worldwide economic crisis pushes all companies, and especially Small and Medium Enterprises (SMEs), to increase their global competitiveness and capabilities by entering new international markets. A promising sector is represented by contract furniture [6] that refers to the supply of products and services for large-sized buildings such as hotels, restaurants and retails. From literature overview it appears to be characterized by a multifaceted commitment determined by the agreement among the general contractor, the owner and the architect; short time to market and lead time; iterative design that still remains unstructured and based on traditional methods and supporting tools; participatory design merging product and architectural design issues; complexity of interactions among all involved stakeholders; long negotiation phases; respect of international standards; and finally insufficient qualification and organization of SMEs human resources [2, 18]. Despite existing advantages, literature is still missing contract furniture-oriented reports about methods to achieve innovation, competitiveness and qualification and tools to support services, globalization, mass-customization and cooperation management in effective ways.

Focusing on enabling tools, numerous Information and Communication Technologies (ICTs) have been developed in the past 10 years to perform market analysis, promote SMEs internationalization, support furniture design and customization, facilitate data sharing and project management among enterprise networks. However, most of these technologies are general purpose, difficulty meet specific contract furniture needs, are not interoperable, do not offer integral solutions that can be adopted by different-sized companies and do not cover the requirements of each development stage. An extensive overview of related works on the topics of marketing intelligence, collaborative product development, Computer-Aided-Design (CAD) and the Internet, Virtual Prototyping (VP) is reported in the paper to demonstrate the main challenges the research proposes [5, 19, 22].

Starting from this complex scenario, the paper illustrates the final outcomes of a project, called DesigNET, involving 17 Italian companies operating in contract furniture, whose aim is to develop a Web-based platform providing a decision support system for contract furniture. It provides the description of results achieved during the three-years research that consists in a technological framework, integrating different web-enabling tools, that allows process stakeholders to identify design market trends and new contract opportunities, propose furniture solutions in an appealing way to capture users attention, provide an online furniture configuration system exploiting virtual prototyping techniques, extract the Bill of Material (BOM) of the customized solution and use the developed virtual prototype to assess its impact in real scenes by adopting Augmented Reality (AR) techniques.

The paper comprehends the works presented in previous researches [3, 14, 15] that faced partial aspects of contract furniture (e.g. respectively the process, item

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configuration, Augmented Reality (AR) potentialities). The overall platform and the way data are kept coherent across modules are here illustrated in detail. Two further software modules i.e. e-marketing intelligence tool and AR-based application integrated with the CAD-based Configurator), that have never been presented before are described. In addition, it also presents two pilot use cases in contract furniture that are used to test the platform usability and reliability: the design of a modular service-apartment and a wellness center. Experimental results demonstrate the achieved platform performance, the potential strengths and the identified weaknesses to be improved. Conclusions provide a list of the main advantages for contract furniture.

2. Related work

2.1. Contract furniture

Contract furniture scope is usually furnishing spaces in a personalized way but repeated the form in a variety of solutions (e.g. hotels, guest houses, offices, bars, restaurants, leisure facilities, retails, stores, ferry-boats). It is regulated by a written agreement (the "contract") that is usually signed between the seller and the buyer and defines time constraints and outputs in advance. Such contract is fundamental to assure the desired outputs in the desired time since the involved partners are numerous and must be coordinated carefully. Furthermore, the process is characterized by the two-fold nature of its activities: furnishing spaces requires on one hand to design single items and on the other one to create modular and flexible compositions. Indeed, it merges traditional product design with interior design and architectural design, and must involve a variety of manufacturers, often coming from different countries, each of them producing a single item [17].

A recent study provides an analysis of AS-IS contract furniture process [13]. The results are summed-up in Tab. 1 where a list of the main features differentiating contract furniture from other industrial design and manufacturing processes is presented.

2.2. Overview of supporting software applications

Companies are aware that the ability to identify in advance market trends and contract opportunities is a crucial factor of success. Useful geo-referenced

Table 1. The main features of contract furniture.

Contract Furniture Features	Description	Key issues to face
Design Goals	Contract furniture aims at designing interiors of residential and/or commercial spaces including furniture items, lightings and environmental systems. Rigid normative standards must be respected as well as fixed delivery time and costs	Mass Customization: Standardized and commercial items must be combined with personalized ones. Personalization is reached via the development of modular and configurable items to reduce cost and delivery time, to adapt solutions to different spaces and pursue the space identity.
Project Management	A contract furniture project is generally launched by an architect and managed by a general contractor, who is responsible for partners' selection and project advance in front of the customer/owner. The architect identifies the proper design solutions to be included in the furniture or those that need to be integrated and customized. The general contractor manages the relationships with the sub-contractor manufacturers/suppliers and supervises economic and temporal project progress.	The team is characterized by an unstructured chain and time scheduling is continuously affected by changes and unexpected events. Cost control is not a trivial task. The conceptual design is complex and multifaceted since it must create a unique project involving commercial and personalized products; the negotiation phase is long since the cost budget is global and comprehends all the furniture; the detailed design phase is long and iterative since the design of each single item is usually defined in relation to other products or services.
Team Composition and Organization	The working team is highly multifaceted and is set-up as an extended and temporary network. In one hand, it is made of people from different companies with different competencies (i.e. marketing staff, engineers, stylists, top managers, CEO) and external partners like designers, commercial agents, installers, mediators, end-users, as well as the general contractor and the main architect. On the other hand, its configuration can change according to external factors, the architects' choices and the time scheduling.	Interactions among all involved stakeholders are intensive and changeable. For instance, during design, interactions allow the definition of a solution appreciated by all partners and compliant with the project requirements, whereas during manufacturing, interactions allow the respect of cost and time constraints. As involved companies are different sized, sometimes human resources are insufficient skilled and qualified to collaborate with foreign enterprises.
Representational media	The means of representation for products and spaces are numerous and vary from abstract and unstructured representations during the conceptual design (i.e. sketches, images, simplified digital models) to CAD-based representations and simulations during detailed design (e.g. structural and thermal performance, kinematics, process simulation, ergonomics), until mock-ups and prototypes during the testing phase. Furthermore, the formats change among the different partners since they usually continue using their tools.	Data exchange and integration is complicated. Collaboration is difficult to be achieved on 3D CAD models that could be useful to manage all process stages. A recent investigation on adopted technologies outlined the lack of dedicated contract furniture tools. The project partners actually use to employ traditional tools and standard methods that could be adopted for mechanical design, furniture design, architectural design, etc.

information regards (i) product design trends, insights into customers liking; (ii) what users do on company websites, (iii) which data different professionals are searching for to perform specific process tasks and finally (iii) macroeconomics indexes and new opportunities to address sales force effort toward the right market.

A system with the aforementioned features is not easily available, as it merges information retrieval with mining approaches, tailored for a specific domain. In the recent years, there has been a hype of industrial and academic research and discussion related to Big Data, but to some extent, research on events prediction dates back to decades ago. Research and implementation on events prediction have been applied in different areas [19] such as customers interest, achieved with data collected by fidelity cards, stock exchange trends, achieved with text mining and news classification [16], geo-political events by text mining, traffic congestion, health condition and disease spreading. Literature overview lacks of a general-purpose prediction system that could be customized for design and market trend analysis in contract furniture sector [9].

Another crucial task in contract furniture is to provide a shared understanding of the product in the real environment and a shared representation of the developed solutions. Indeed, decision-making activities through all the design process are crucial for the final product success but currently there are limited computational tools available to provide better support to the designer especially at the earlier stages of the process and in collaborative contexts [30]. Despite numerous researches focused on enabling technologies to support collaborative design and product model sharing [12], none of them specifically address contract furniture needs. Most systems providing a shared and distributed workspace where designers and manufacturers can access a product model and check the status of their assigned tasks [23], are strongly product-centered and do not offer an integrated environment for data management, product modeling, project review and decision-making. From a recent market survey [14] it is possible to classify them into Web-based configuration systems, that allow a 2D-3D environment to be created where furniture items can be positioned and rendered, dedicated CAD-based configuration systems, that allow 3D product models to be imported and configured, co-design tools to visualize and mark-up 3D models in a shared modality, and finally CAD-based plug-in applications to manage product variables and assembly configuration, create relationships among product features and dimensions, and handle modular assemblies. Notwithstanding the above-mentioned functionalities, most systems lack of project management tools, online space configuration features, BOM management and project scheduling. Moreover they are not easily customizable, interoperable, flexible and cost-effective and scarcely fit with the needs and competences of SMEs involved in the contract furniture chain.

Another important issue to create agreement at the negotiation and decision-making stages is the verification of the custom solutions in real contract scenarios. In this context, the application of Augmented Reality (AR) in conceptual design has been proved to be useful in the simulation of products in order to take decisions and get more accurate evaluations considering other stakeholder of the product [2]. Indeed, AR techniques offer the opportunity to achieve this goal as they allow virtual configurations and real spaces to be superimposed [1]. The result is an enriched environment where digital information is inserted in a predominantly real world view. In fact, if the virtual objects arrangement is displayed in the real world, no abstraction activities are required to imagine the final results. In addition, the better understanding of the final result allows the user to directly interact with the environment to be planned and to be fully involved in the arrangement of the spaces.

AR environments can be originated from marker-based tracking toolkits (e.g., ARToolkit, ARTag) or markerless toolkits (e.g., D′Fusion in T-Immersion Corp.), and more recently by mobile context-aware methods (e.g., Layar, Junaio, and Wikitube) that can bring AR into mobile and field contexts. A good state-of-the-art review of mainstream studies in AR and a reference architecture layer framework of AR system are presented in [29]. In all cases, the application of AR can reduce cost and time and also improve the quality of product evaluations integrating the context elements and a more natural interaction with virtual elements [30]. Some efforts developing computational tools to evaluate concepts along the product design phase in order to short times and resources have been identified: from a mixed reality application for the aesthetic design that allows the construction of free form surfaces [10], to an AR application that shares objects to enable collaborative interior design among multiple users with different roles and locations, working together [1], to an AR system that uses a Head-Mounted Display (HMD) to provide high-quality image and response time for car design and rendering [15], to an AR system for validation of design concepts by VR mock-ups [Osorio Gomez et al., 2012], to an AR application for Android mobile devices for getting feedback of a target user in order to enhance the evaluation of aesthetical response in the conceptual design of discrete products [2].

Today, Computer-Aided tools allow an easy rearranging of virtual furniture and equipment in a virtual environment to support Space Planning (SP) in AR applications [7, 17, 21]. Using these tools a designer can easily evaluate the encumbrance, the position and the orientation of each object with respect to the dimensions of the room. However, this simplified representation does not allow the correct evaluation of other criteria, such as the aesthetic impact of the final layout due to the adopted low-level realistic rendering techniques [5]. Some attempts to overcome this limitation are offered by mobile AR that is still under investigation [11, 23]. However, performing SP activities in an AR environment implies using systems that allow the tracking of the whole working area. In this way, it is possible to correctly place virtual objects according to the real environment. High-accuracy systems, such as the optical ones, are able to cover an entire room but require the installations of several and expensive devices. Cheaper tracking systems, instead, use Computer Vision (CV) algorithms to detect the camera. Some of these algorithms estimate the camera pose by detecting natural features in the environment [4] but they cannot work in case of completely empty spaces. Another more reliable solution is by adding known objects, such as fiducial markers, within the real scene. However, also in this case, the tracked environment requires to be structured by positioning and calibrating several markers in the working area [8]. This activity is time-consuming and not flexible.

3. The desigNET general framework

The approach adopted to define the general framework to overcome the actual limitations of the above-mentioned tools for contract furniture is based on the following steps:

Step 1. Investigation of the AS-IS contract furniture process by questionnaires and interviews submitted to the involved industrial partners. Structured questionnaires allowed the current process to be mapped and the stakeholders' needs to be highlighted;

Step 2. Elicitation of user requirements by expert analysis: starting from the AS-IS process model and the investigation results, user requirements are elicited by a heuristic evaluation carried out by experts. The TO-BE process is defined to overcome the current criticalities and create a list of requirements. Requirements are weighted according to a 5-point scale to take into account user needs' satisfaction;

Step 3. Benchmarking of the most suitable technologies for each process stage. Available technologies are analyzed according to their features and correlated to user requirements by adopting the Quality Functional Deployment (QFD) technique. A correlation matrix is used to evaluate how systems are able to satisfy each requirement and to identify the most suitable technologies. Correlation considers the requirement weighting to calculate a relative importance value for each analyzed tool;

Step 4. Selection of the most proper technologies according to the user needs and their integration into a unique platform to facilitate market investigation, furniture item design, virtual prototype creation and evaluation in real contexts of use.

As described in [14], Step 4 leads to conceive a platform made of four modules that are separately developed and then connected to guarantee a coherent workflow and data sharing (Fig. 1):

- E-marketing intelligence module is a user-friendly Web application to analyze the market trends as well as competitors' offers, and to highlight contract furniture opportunities by detecting and elaborating data from the web;
- Virtual Prototyping-based module to visualize companies' solutions and to configure both each furniture item and the design space;
- Co-design module, to collaborate on 3D models to create custom solutions;
- AR-based module, to support the design evaluation of the configured items and environment by superimposing virtual prototypes and real scenes.

The contract furniture process starts with the introduction of product models in the platform through the manager application (i.e. Definer Module) to make them available on a web-based virtual catalogue (i.e. Virtual Marketplace), where final users (e.g. architects or designers, but also final users and buyers) can search for a specific solution, navigate it, configure its aesthetic and technological features. Once the platform has been accessed, two workflows are contemporary activated: the configuration flow and the business analysis flow. The former supports users in configuring their spaces by using the proposed catalogue of products and contacting the companies in case of personalization and integration with other products. The latter analyzes Internet sources according to the users' preference and needs to provide marketing information, to be used by the manufacturing companies.

A low-level configuration flow already starts in the virtual catalogue. When the user selects a solution, he/she downloads data sheets, creates its variant by combining a set of predefined options (e.g. finishing,

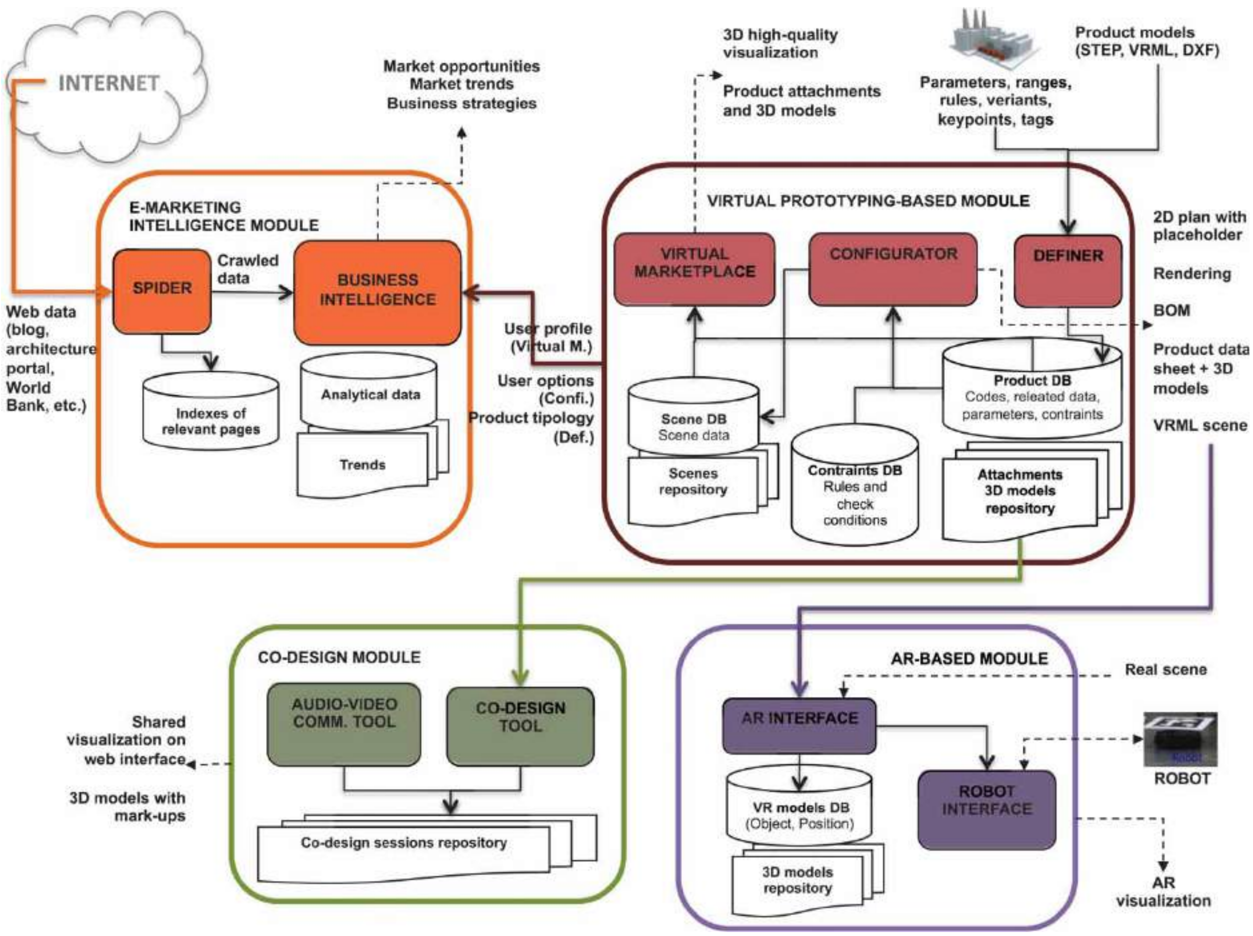

Figure 1. The DesigNET general framework.

color, accessories) and includes it in his/her personalized catalogue. A high-level configuration of each single item and of the overall space can be achieved by the use of the Configurator. It allows the user to represent the virtual environment to be designed and support its configuration by inserting products from the marketplace, the personalized catalogues and local databases. Such a tool allows the creation of a virtual simulation of the configured space to test both the aesthetic impression and the technical feasibility. The configuration process can be supported also by two further modules, which enable respectively real-time collaboration on 3D models and environment estimation in a realistic context. The first module (i.e. Co-design) allows the users to contact a specific manufacturer and collaborate with its technicians to define an ad-hoc solution. The second module (i.e. AR-based) imports the virtual space realized by the Configurator and projected it on a real space with the final aim to validate the solution by AR prototypes before building costly physical prototypes.

The business analysis flow considers the information about the users' characteristics, needs and actions, and exploits them to carry out an oriented market analysis on Internet sources. Necessary information are retrieved by a semantic-based tool (i.e. Spider) and elaborated by an intelligent tool (i.e. Business Intelligence) in order to identify the market trends and the market opportunities according to the user profile and the configuration options expressed by the user. Manufacturers can use it to start with the conceptual design of novel solutions.

3.1. E-marketing intelligence module

The E-Marketing Intelligence Module is a Web application built around 4 main user stories and related information to easily visualize, identify and analyze geo-referenced information.

The system is organized into two main components (Fig. 2a) that are the spider and the business intelligence. The spider is responsible for retrieving information available over the Internet to access a variety of Web sources to collect information about contract opportunities, economic outlook and design trends. It operates as an integration layer that reads and parses heterogeneous Web sources, and stores the retrieved information in a relational DBMS. The business intelligence is responsible

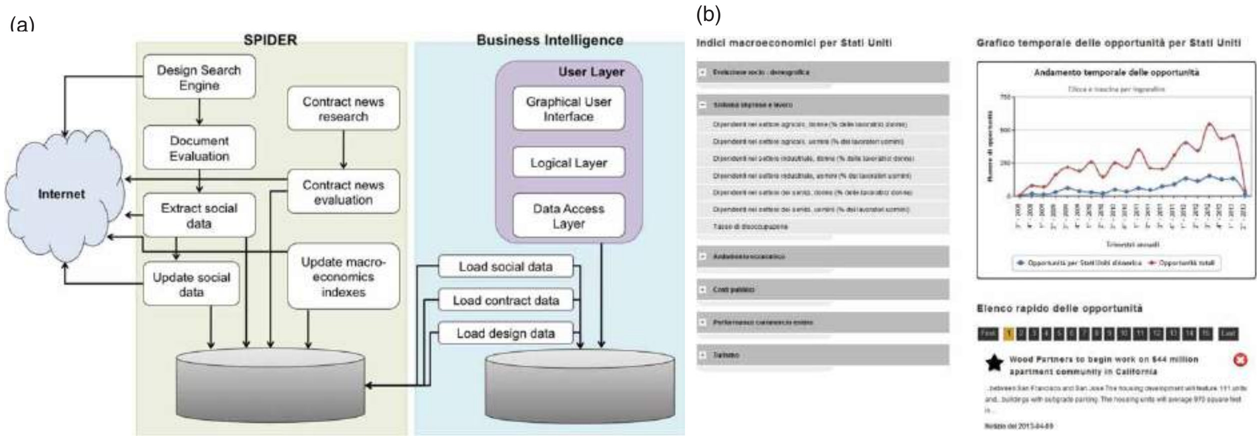

Figure 2. (a) The module architecture and (b) "Macroeconomic indexes and opportunities" web page.

for connecting to the spider database, perform the ETL process (e.g. extract, reorganize and historicize retrieved information) and store data in a data warehouse optimized to quickly return to users queries through the use of materialized views and indexes. Furthermore, it provides a Web-based user interface that displays information and analysis outcomes through a number of charts. The whole system is based on a client–server interaction, where each component acts as a client when receiving information from actors in a higher level of the chain, and act as a server when providing information to clients in a lower level of the chain. Each component is characterized by different software modules, communicating each other or isolated, which perform the individual subtasks that assemble any single service. Both the spider and the business intelligence components run on two low-level servers and are hosted on two EEEBox virtual machines as described in detail in [9].

Geo-referenced information to perform market analysis is classified as follows:

- Design market trends with a focus on specific products of interest with related aesthetical characteristics (e.g., given a product of interest, show its popularity and customers liking, show which are the most popular aesthetical characteristics associated with customers liking). Data on market trends are retrieved from online specialized magazines, newspapers in general, social networks, architects' websites, interior design portals and interior design blogs thanks to a semantic-based knowledge discovery tool;
- Competitors' analysis achieved through competitors popularity analysis (e.g., show competitors products popularity and related aesthetical characteristics). Competitors web sites and blogs are used as sources.
- Contract opportunities globally available and/or available in a specific country with a focus on the economic situation and tourist trends (e.g. show contract opportunities, GDP and Tourism Spending in a specific country). Information regarding macroeconomic indexes and tourism trends are retrieved from national and international institutional websites (World Bank, International Monetary Fund, World Travel & Tourism Council); information regarding contract opportunities are retrieved from web sites specialized on news regarding worldwide contract opportunities.
- Users navigation data on the company website to show most viewed products with related aesthetical associated characteristics or tags used in the search form. Tracking users navigation behavior on the marketplace and companies' websites allows the collection of this information.

All gathered data are aggregated per quarter/year to better highlight temporal fluctuations.

The user can access the specific section of the E-Marketing Module, select for instance "table" from the drop-down list of products and visualize charts regarding its popularity, design trend and most popular aesthetical characteristics. Moreover he/she can select a country and have a look about available macroeconomics indexes to have a concise knowledge regarding economic situation and tourism trends (Fig. 2b).

3.2. Virtual prototyping-based module

The Virtual Prototyping-based module consists of three tools, a virtual catalogue to propose furniture solutions, a design automation system to configure the space and the selected items and finally a system manager to support companies in storing models and related documents, arranging configurations and setting constraints and variation parameters.

The 3D virtual catalogue is a web-based market place where the user can navigate across an extensive collection of furniture items and integrated solutions (Fig. 3a). He/she can configure product variables and view his/her custom solution in terms of colour, surface finishing, dimensions and auxiliary functions (Fig. 3b). Each item is correlated with a technical documentation made of 2D drawings, 3D models, and manuals and data sheet. User registration is imperative to download data. The software allows user identification, authentication and tracking to achieve a complete profile useful for marketing purposes. The programming language is AST.NET to create dynamic Web applications and services, WebGL libraries for rendering interactive 3D graphics of product items, scene and solutions. The Virtual Catalogue is compatible with all well-known web browser (e.g. Safari, Firefox, Explorer).

The Interior Design Configurator is a CAD-based configuration engine to create a personal project, import 3D architectural space models (e.g. room, store, hall), populate them with items selected from the Virtual Catalogue and finally configure them according the user needs in terms of aesthetics, performance, functions, etc. (Fig. 3c). Item configuration and positioning into the space follow manufacturers' guidelines and technical constraints. A knowledge-based set of rules are implemented to explicit the relationships among items and the environment [15]. The Configurator is a desktop-based application and is synchronized with the Virtual Catalogue to keep the selected products and integrated solutions ever updated. The adopted programming language is VB.NET to manage 2D and 3D geometries, product variants, configuration rules, constraint check, user roles and permission databases, BOM creation and data exchange and WebGL libraries to realize 3D graphics.

The Data Manager is the manufacturer-dedicated interface as it allows him/her to upload and define offered items and solutions, feasible variants and the possible ranges of product parameters' modification (Fig. 3d). For each item the manufacturer provides a 3D model and its technical documentation, indicates product characteristics in terms of materials, surface finishing, functions, specifies options, defines customizable features and ranges of variations and finally adds installation and configuration constraints.

The Data Manager is a desktop-based application that exploits the same programming language and framework of the configuration. It is synchronized with all system databases.

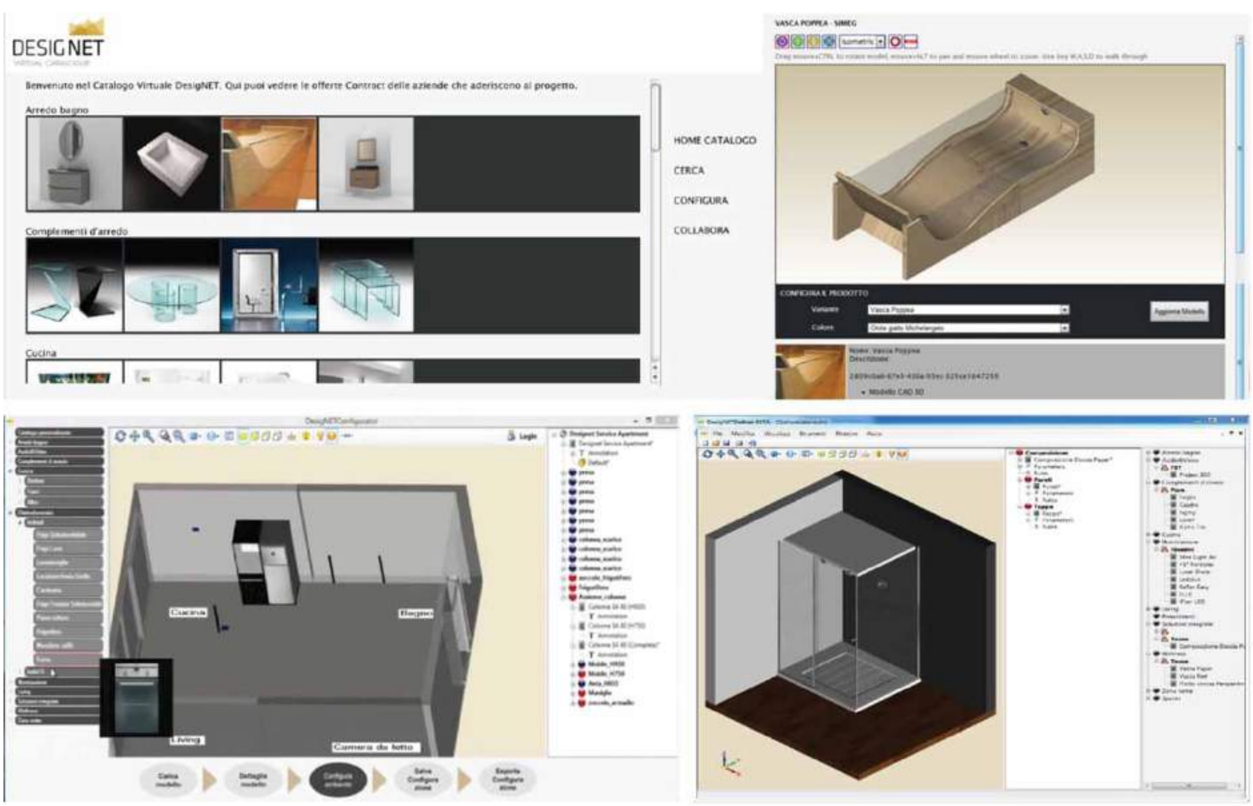

Figure 3. Virtual Prototyping-based module interfaces from top-left to bottom-right: (a) Virtual Catalogue home page, (b) Product configuration in the Virtual Catalogue, (c) Configuration interface, and (d) Data Manager user interface.

3.3. Co-design module

The Co-design module allows participants to collaborate on shared 3D models and supports users in creating personalized items with the fundamental support of the manufacturing company. The module is accessed by the user workspace: he/she launches a co-design session and invites the project team members. Product models and data can be directly taken from the project area or from local databases. The module integrates different commercial software packages: a collaborative CAD-based tool (i.e. AutoVue by Oracle), an instant messaging and video-conferencing tool (i.e. Skype), and a web-based workspace area developed by HTML technology. The module allows real-time collaboration to be managed for technical design reviews on many different types of documents: CAD files, images, office files, hypertexts, etc. The session participants are able (Fig. 4a):

- to open native file formats (e.g. .dwg, .dwf, .CATpart, .CATproduct, .prt, .asm, .jt, .iges, .step, .stl, .dpf, .dpl, etc.);
- to share the product models in real time with multiple users that is simultaneously on line;
- to collaborate also on huge assemblies and retrieve all attributes that allow identifying suppliers, developers, materials, manufacturing cycles, etc.;
- to analyze the shared product model from a common viewpoint and from different perspectives according to the design aspect under investigation (ergonomics, aesthetics, functional, manufacturing, etc.);
- to mark-up and apply notes directly on the shared model and visualize also comments from other users participating in the session;
- to save the mark-ups on the shared files in the platform databases;
- to exchange the control of the scene;
- to communicate remotely during the working session by audio and video conferencing;
- to communicate via instant massaging;
- to access the product or project information while collaborating on the 3D product model.

3.4. AR-based module

The design of the AR system is based on a flexible and cost-effective architecture [20]. The AR system can be used in different kinds of SP contexts, can be easily installed in different working environments and can easily manage various virtual objects. It consists of two components as shown in Fig. 5b: an AR Interface and a Robot Interface. The AR Interface includes a laptop and an external USB camera installed on a trolley. In this way the AR Interface can be easily moved within the real environment that a user aims at furnishing with virtual objects. The Robot Interface consists of a mobile robot equipped with a fiducial marker, which is used for tracking purposes. This configuration is used to extend the AR working area. The mobile robot is an iRobot Roomba 560, which is a commercial mobile robot, robust, and easily controlled remotely. The communication between the robot and the laptop is implemented by using two XBee

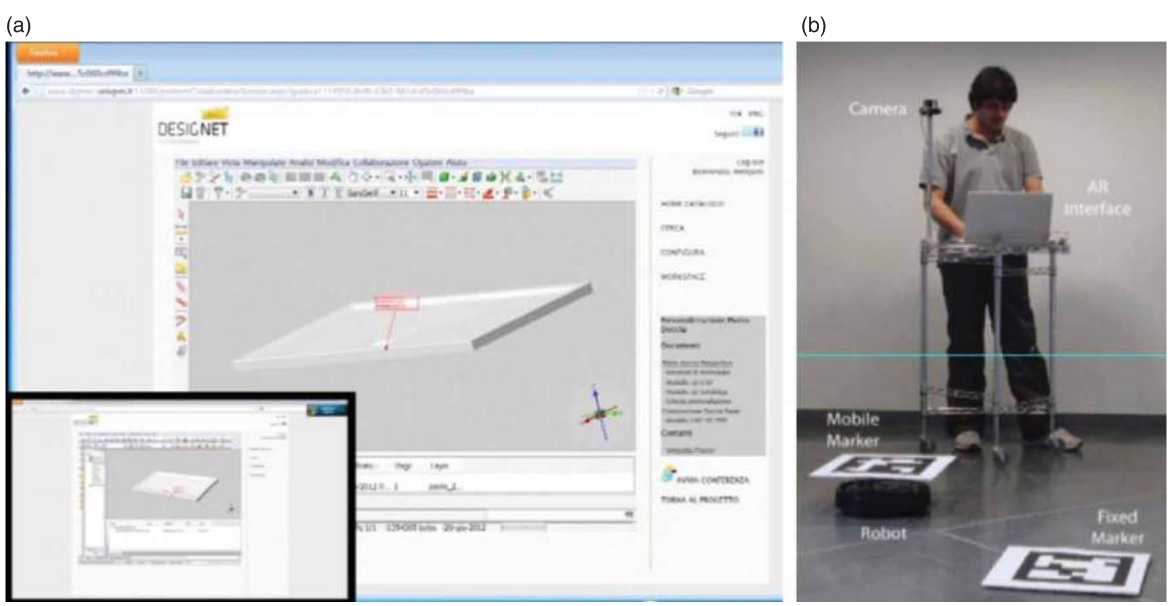

Figure 4. (a) The Co-design user interface, and (b) the AR-based module architecture.

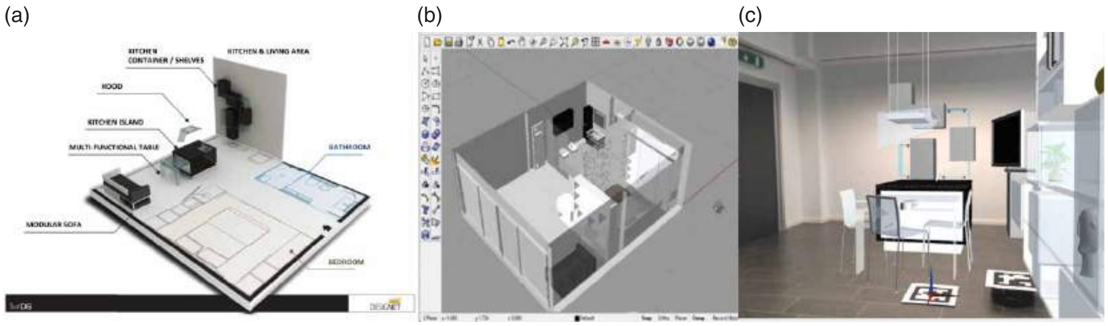

Figure 5. The design of the serviced-apartment: (a) a view of the concept in the Virtual Catalogue, (b) its representation by the Virtual prototyping-based module and (c) the AR-based module.

devices, which allow a wireless bidirectional transmission of the data coming from the serial port mounted on top of the robot to the USB port of the laptop. The user can remotely control the robot position either manually or automatically. The AR system estimates the pose of the camera in the environment by merging data coming from the mobile robot and data coming from the marker-based tracking. One marker is fixed and placed on the floor of the room (fixed marker) and defines the position of the absolute reference system. The AR system estimates the camera pose according to the position of this marker. Moreover, the fixed marker is also used to set the initial position of the mobile robot, so that the robot has a position that is always coherent with the defined reference system. Each time the fixed marker is framed by the AR system, the data obtained by its tracking performed by means of a standard marker-based approach are used to estimate the camera pose. The other marker is placed on top of the robot (mobile marker) and can be moved, in an automatic or manual mode, every time the user moves the AR Interface to frame another part of the scene. In this way, this marker can be always visible to the camera. Each time only the mobile marker is in the framed scene, the AR system estimates the camera pose by using also the data coming from the robot. In this way, the marker tracking is performed on a mobile support, whose location is known by means of the odometric data, which the robot continuously sends to the AR Interface in order to convey its position. So the camera pose is calculated as a linear combination of data gathered from the encoders and the mobile marker tracking.

The AR system requires an initialization phase that consists of calibrating the initial position of the robot according to the reference fixed marker. Since the environment is not structured, the initialization is very fast and takes less than one minute. In order to perform the initialization, it is necessary to frame both the markers by the camera. Then, once the reference marker is arranged in the defined position of the working space and the robot is placed on the floor, the AR system automatically performs an auto-calibration and is ready to be used.

The AR Interface includes additional functions, which support SP activities. The user can see the augmented environment through the main window of the AR Interface. The visualization functionality is based on the above-described tracking approach for getting spatial and temporal coherence between the real environment and the virtual objects. The user can handle the virtual objects in the real environment by means of a dedicated Graphical User Interface (GUI), which is integrated in the AR Interface. The GUI shows in a preview window all the available virtual objects, which are stored in a database. The user can select and add a virtual object to the real space: the object is automatically placed in the scene and visualized in front of the camera point of view, at a distance of 1.80 metres. Then, the user can change the object position in order to correctly place it in the desired location. This operation is performed by means of six menu buttons, two for each axis, which enable the user to modify the position and orientation of the virtual objects according to a step-by-step value change.

The AR system also allows to upload designed plans of the environments, which are useful for having at disposition a further reference for locating the virtual objects in their correct position. These plans are previously prepared by the user and, once loaded, are visualized on the ground of the working space. Finally, the system allows users to configure virtual lighting conditions. This function is important, since a correct illumination enhances the coherency between the real and the digital worlds, and consequently the sense of immersiveness of the user in the augmented environment. So, the designed space is better perceived, and the AR interface helps in evaluating the aesthetic impact of the virtual objects more effectively. The light settings are externally designed according to the different real illumination of the working environment, and then loaded into the AR scene.

Finally, the AR Interface allows saving the current layout including the virtual objects and their position. The user can store different configurations in his/her workspace and switch from one to another, in order to quickly evaluate the possible furnishing solutions, or show the space planning to other people (e.g., customers).

4. Experimental evaluation and result discussion

The analysis of the platform usability is carried out into two steps: a heuristic evaluation involving five Academia experts in Human-Computer Interaction (HCI) and Contract Design to optimize the first user interfaces, and a task analysis involving 52 sample users employed in company partners to assess the platform performance. Involved people come from marketing and technical departments (i.e. project managers and industrial designers), and from design studios (i.e. architects).

The tasks are defined within two different use scenarios: a serviced-apartment and a wellness center. Both need to be designed and items configured to meet target user requirements.

The evaluation is carried out according to an experimental protocol consisting of two sections:

A. Expert evaluation by heuristic evaluation: the analysis focused on the interface optimization and is conducted by Heuristic Evaluation. The main results allowed detecting and correcting the main errors of the user interface with regard to graphics, semantics and dynamics;
B. Task analysis with users, which in turn consists of the following six phases:
   1. Scenario definition: two scenarios are selected, a serviced-apartment and a wellness center. The first one is a representative scenario for residential contract design and refers to any kind of apartment generally used for short or long stays by managers and business man/woman. Serviced-apartments are usually less expensive than a traditional luxury hotel room, and designed to offer higher comfort and privacy. The second one represents a growing business for commercial contract design and merges a proper public commercial area with a more characteristic wellness area (e.g. thermal treatments, massage areas). Nowadays both kinds of accommodation are very common and represent a good business for companies operating in contract furniture design;
   2. Task definition: 10 tasks are selected to test the main platform functionalities. Tasks refer to the different platform modules, in particular to the most important functions of the e-marketing, virtual marketplace and virtual prototyping modules. Selected tasks are reported in the following tables (Tab. 2 and 3). Obviously tasks are

Table 2. Usability results for industrial users.

			TASKS										
			E-marketing			Virtual Marketplace			Virtual prototyping & AR				
INDUSTRIAL DESIGNERS & MANAGERS			*To identify the most preferred products/solutions*	*To analyse the main market trends*	*To define the main economics indicators*	*To create a personalized virtual catalogue*	*To configure a product and download the related technical documentation*	*To creare a new co-design session*	*To configure an entire space / functional area*	*To insert new products within the 3D model*	*To export the BOM of a configured solution*	*To creare a new product and its variants*	
Usability Dims.	***Metrics***	***Unit of meas.***	***T1***	***T2***	***T3***	***T4***	***T5***	***T6***	***T7***	***T8***	***T9***	***T10***	***AVERAGE RESULTS***
Efficiency	Task completion	%	98%	86%	92%	99%	89%	88%	92%	79%	90%	85%	**90%**
	Support requests	no.	2.5	3.2	1.5	1	0.5	1.5	2	2.8	1.2	2	**1.82**
	Errors	no.	0.5	1	1.5	0.2	0.5	0.5	1	2.5	1.2	2.5	**1.14**
Effectiveness	Execution time	min.	25	38	40	60	35	28	105	183	24	92	**63.00**
Satisfaction	Perceived difficulty	1–5	2.50	2.00	2.50	1.20	0.50	1.80	2.50	2.80	1.50	3.50	**2.08**
	Sense of frustration	1–5	1.00	1.50	2.00	1.20	0.80	1.50	2.20	1.50	0.50	2.50	**1.47**
	Usefulness	1–5	3.20	4.00	4.80	3.00	4.20	3.50	4.80	4.80	4.20	4.00	**4.05**
	Order	1–5	3.80	2.50	3.00	4.80	4.20	3.00	3.80	4.20	4.50	3.50	**3.73**
	Pleasantness	1–5	3.20	3.50	2.80	3.60	4.80	3.50	4.20	4.80	4.00	3.50	**3.79**
	GLOBAL SATISFACTION												**3.02**

Table 3. Usability results for architects and stylists.

ARCHITECTS & STYLISTS			TASKS										
			E-marketing			Virtual Marketplace			Virtual prototyping & AR				
Usability Dims.	Metrics	Unit of meas.	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	AVERAGE RESULTS
Efficiency	Task completion	%	96%	90%	80%	100%	99%	79%	98%	92%	95%	92%	**92%**
	Support requests	no.	2	3.5	1	1.5	1	1.8	2.5	2.5	1.2	2.5	**1.95**
	Errors	no.	0.5	1	1	0	0.5	1	0.5	1.5	0.8	1.5	**0.83**
Effectiveness	Execution time	min.	30	40	45	48	30	30	85	124	20	73	**52.5**
Satisfaction	Perceived difficulty	1–5	2.50	1.80	2.00	1.00	0.60	2.00	2.20	1.50	1.20	2.00	**1.68**
	Sense of frustration	1–5	2.50	2.00	1.80	1.50	1.00	2.50	2.80	1.50	1.00	2.20	**1.88**
	Usefulness	1–5	2.50	4.20	3.00	3.50	4.90	2.50	4.20	4.00	4.00	4.50	**3.73**
	Order	1–5	2.50	2.00	1.80	4.00	4.20	3.00	3.80	3.50	4.50	2.50	**3.18**
	Pleasantness	1–5	3.00	3.20	2.00	3.60	4.00	3.20	4.00	4.20	3.50	3.00	**3.37**
	GLOBAL SATISFACTION												**2.77**

referred to the specific scenario and its target market;

3. Metrics definition: metrics refer to the three usability dimensions (efficiency, effectiveness and satisfaction) according to ISO principles [10]. As a consequence, for each task metrics are both subjective and objective. Objective metrics refer to task completion (%), number of support requests, number of errors and execution times. Subjective metrics refer to perceived difficulty, sense of frustration, usefulness, order and pleasantness;
4. Task execution and feedback collection: users are involved to execute the tasks and are monitored by experts via direct observation and Video Recorded Analysis (VIA). For each user, metrics about efficiency and effectiveness are measured and properly valorized during tasks execution by experts. After the tests, users are submitted to a post-hoc questionnaire exploring the satisfaction metrics, expressed according a 5-point Likert scale;
5. Results elaboration and synthesis of the results: results are considered for all users and elaborated to extract average value. Results from company managers and architects are expressively separated to analyze the differences.

4.1. The experimental results

Figure 5 shows the serviced-apartment concept and its representations by adopting different platform modules.

For each use case, all the design phases were carried out with the support of the DesigNET platform, from the market analysis to the conceptual design, until the detailed design of the different areas. In particular, the e-marketing intelligence module was adopted to investigate the target market and identify the market trends for each case; the Virtual Prototyping-based module was used for product design and the creation of product alternatives and variants, as well as for the design and configuration of digital environments; the co-design module is adopted for the creation of integrated solutions where different companies and partners are involved and different products, designed by different stakeholders, are integrated; and finally the AR-based module is used to test the designed solution into a realistic environment and superimpose virtual and physical prototypes.

Tables 2 and 3 present the average results of all users for the selected tasks; the last column collects the average value on all tasks. In particular, Table 2 refers to the usability results collected from the technical staff of industrial partners, while Table 3 refers to architects and stylists response.

Results are arranged in a table according to the three elements of usability (i.e. efficiency, effectiveness and satisfaction). The achieved task completion is about 91%. Architects register a lower percentage for task completion than technicians and industrial designers during the use of the e-marketing intelligence and the co-design modules. Their requests are mainly oriented to deepen the functionalities of the platform and not to ask assistance. This fact demonstrates the interest they have for a tool supporting their daily work. The Virtual prototyping-based module is perceived as the most complex tool by architects as demonstrated by the registered execution time. Contrarily, designers and technicians are more confident in the use of such module as demonstrated by the lower execution time and the higher satisfaction values. Globally, the average satisfaction value is 3.02 for industrial employees and 2,77 for architects.

5. Conclusions

The research proposes a challenge in supporting tools to address an effective collaboration among all involved stakeholders at the different stages of contract furniture design, identify market trends, reduce delivery times and customize proposed solutions. A technological framework is presented. It integrates different modules for market analysis, web-based virtual prototyping to meet contract furniture requirements. Experimental results demonstrate that the implemented platform is affordable and easy to deploy from non-expert users such as designers, contractors and final consumers. Some advantages can be achieved by introducing such platform in contract furniture such as:

- fostering integration and cooperation among partners with different sizes, organizations, competences and roles with the benefit to manage the dynamism and diversity of the contract furniture cluster;
- creating a communication space to collect, exchange and share data at different levels of details and belonging to different domains of knowledge;
- implementing a Virtual Prototyping-based approach that enables designers, economists, architects and manufacturers to effectively configure solutions that respect multi-domain rules;
- providing a low-cost web-based system that can be easily integrated in different operative contexts where diverse ICTs solutions are adopted to design each single piece of the furniture space;
- minimizing time to develop a BOM of the overall contract furniture with 3D models and related data sheets of the customized solutions.

Tangible cost/performance benefits from the implementation of the proposed technological framework concern an increased attractiveness of traditional e-commerce solutions companies are adopting, the keeping of actual clients' business, the enhancement of company's visibility and perceived innovation, the extension of the design and supply chains' network, the possibility to enable the distributed organization to respond more quickly to change, the speed-up of business processes and the reduction of some administrative tasks (e.g. easy access to customer information, faster retrieval or delivery of information) and finally the achievement of significant timesaving (i.e. estimated about 30%) and related costs for custom items' development and subsequent delivery.

However, a field evaluation becomes imperative to quantitatively estimate the benefits. For this reason future work will be focused firstly on the integration of the developed platform with the ICTs adopted by the involved partners and then on the collection of further pilot cases to assess the achieved performance in terms of reduction of external and internal communication expenses and of revenues generated either from current business supported by the proposed framework and from new initiatives deriving the novel approach.

The final aim of the overall project is to commercialize each single platform module and in some case to freely provide it to customers, mainly designers and architects to foster collaboration.

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