An Ontology-based Approach to Product Customization

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Abstract. Mass customization refers to the increase in variety and customization of the manufactured products and services. It is now economically feasible thanks to the availability of computer-aided manufacturing systems, which allow people to customize standard products, and to Internet, through which many online retailers now operate, thus eliminating the constraints of physical shelf space and other bottlenecks of distribution that, in past years, prevented the production of niche products because of their high production costs. To permit mass customization, several software-based product configurators are available on the Web: they guide people in adapting a product to their needs and desires. A drawback of such configurators is the limited range of changes permitted. We present in this paper a system that gives people more freedom in creating products that best fit their desires, thanks to the use of an ontology, which models the possible product compositions that users can perform. The proposed solution is shown through a case study, which refers to furniture production.

Keywords: product customization, long tail, end-user development, ontology, knowledge management.

1 Introduction

Mass customization is the new frontier in business competition for both manufacturing and service industries. It permits an increase in variety and customization of the manufactured products and services, avoiding cost increase. This is made possible by the use of computer-aided manufacturing systems, which combine the flexibility of individual customization with the low unit costs of mass production processes, i.e. the production of large amounts of standardized products [1].

Mass customization is defined as the method for “effectively postponing the task of differentiating a product for a specific customer until the latest possible point in the supply network.” [2]. Different types of mass customization have been proposed in literature [3]. One of these types is *adaptive customization*: it means that companies

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produce standardized products, which customers can modify by themselves to produce a version customized to their needs and desires [4], [5].

In order to allow adaptive customization, several software-based product configurators, also known as mass customization toolkit, design kit, or toolkit for user innovation and design, are now available on Internet: they guide users (i.e. customers) to add or to modify features of a product in order to make it more suitable to their needs and desires [6]. Examples of product configurators are provided by IKEA [7] and Nike [8]. By using the IKEA configurator, the customer can select a product from the catalogue, e.g. a wardrobe, and change some of its features, like the type of wood, the color, and the size. A limitation of such configurators is that the changes customers can perform are constrained within a limited range of possibilities [6], [9]. Referring again to the IKEA example, the user cannot add a third drawer to a wardrobe if it is designed with only two drawers.

Some people may feel this as a strong limitation to their creativity and needs. The approach we present in this paper aims at providing users with software environments in which they will have more freedom in creating products that best fit their desires. The motivation came from a company working in the Puglia region, Maiellaro s.r.l., which produces classic style furniture. This type of furniture is usually very expensive, thus the company would lose a lot of money if it remains unsold. To cope with this problem, their business process is very different than traditional furniture producers. As it will be described in more detail in Section 4, the company produces only pieces of furniture, which are ordered by customers, who look at the company catalogues and provide a sketch of each piece of furniture they want, which may be composed by parts chosen from different items in the catalogues, and assembled together.

By considering the case study of Maiellaro company, we describe in this paper a system, which allows customers to create the wanted furniture. According to the SSW methodology [10], [11], the system is composed by a network of software environments, each personalized to culture, skills and needs of the stakeholders involved in the design. Customers have much more freedom in designing their furniture, thanks to the use of an ontology that models the possible composition of different parts in a whole piece. The proposed solution can be applied to different types of products. It goes beyond the current mass customization approaches, like those implemented by product configurators, keeping low production costs and, at the same time, supporting creativity of customers and increasing their satisfaction in getting a product much closer to their needs and desires.

The paper is organized as it follows. Section 2 summarizes current trends of Mass Customization and the Long Tail model. Section 3 discusses current product configurators. Section 4 presents the Maiellaro case study and Section 5 the ontology-based approach. In Section 6, the developed system prototype is illustrated. Finally, Section 7 reports conclusions and future work.

2 Mass Customization

Our economy is increasingly shifting from a focus on a limited number of mainstream products and markets, going toward a huge number of niches. As the costs of production and distribution fall, there is less need to lump products and consumers into one-size-fits-all containers. Mass customization is the new frontier for both manufacturing and service industries; it is now possible since computer-aided manufacturing systems permit people to customize standard products, thus keeping the low production costs of mass productions [5], [6].

The demand for products not available in traditional bricks and mortar stores is potentially as big as for those that are. Without the constraints of physical shelf space and other bottlenecks of distribution, narrowly-target goods and services can be as economically attractive as mainstream fare.

Researchers refer to the Long Tail as the right part of the chart represented in Fig. 1, which shows a standard demand curve of any industry [12]. The horizontal axis represents products that can be manufactured by a certain industry (on the left the most common products, on the right niches products); the vertical axis represents sales frequency, dependent on the product popularity of each product (on the left most common products, on the right niche products). Mainstream products ("hits"), which

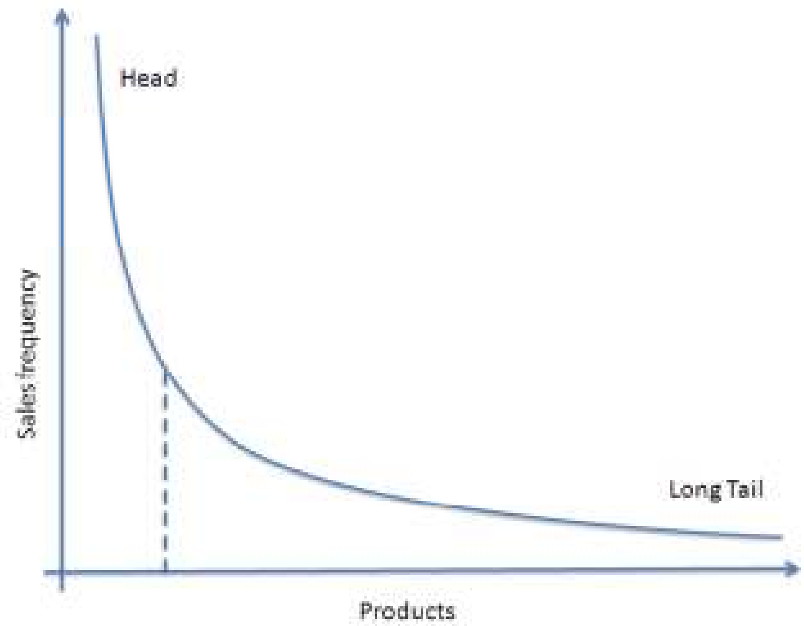

Fig. 1. The Long Tail model (adapted from [12])

have dominated our markets for most of the last century, are in the left higher part of the curve (Head). The right lower, but longer part (Long Tail), refers to niches of products, and indicates where the new growth is coming from, now and in the future.

According to traditional retail economics, stores only stocks the likely hits, because shelf space is expensive. In recent years, many online retailers, like Amazon [13], appeared on the market: they can stock virtually everything, so the number of niche products that are now available is larger than the hits by several orders of magnitude. These millions of niches are the Long Tail in Fig. 1; they have been largely neglected so far due to economic reasons. The variety of world population pushes towards niches because they satisfy narrow interests better. Today the Web has released the constraints of physical storage space, making possible to offer consumers many more choices.

In [12], an analysis of the sales data and trends in the digital entertainment market has shown that its economy is going to be radically different from today's mass market. While the 20^{th}-century entertainment industry focused on hits, the 21^{st} will focus on niches. It is even claimed that many of our assumptions about popular taste are artifacts of poor supply-and-demand matching, which is the market response to an inefficient distribution.

It is widely acknowledged that the new trend addressing the Long Tail is not limited to the entertainment market and will affect all manufacturing industries. An example referring to furniture manufacturing is reported in this paper.

3 Product Configurators

In the last years, companies have been taking into account opportunities that the long tail can give. In order to provide individual customers with unique products, mass customization strategies and tools have been developed.

Among the tools available on the market, product configurators are widely used and offer customers the possibility of adapting, to some extent, a product to their needs and desires by using a direct and visual version of the configured product. The aim is to let users to personalize the product [1], [6], [9]. A configuration is usually obtained in several steps because there may be several aspects of the product that can be configured, e.g. color, material, writings, etc. The product configurator is therefore a Wizard where every configurable aspect of the product is handled in a single step.

A product configurator is a highly visual interactive environment where users configure the product by direct manipulation. Every time users make a change, they immediately see the results. Users can “play” with products and “see” all available options. Finally, they obtain a view of the product they may want to order.

We analyzed several product configurators available on the Web. An example is NIKEiD, the shoe customization tool of Nike. Once a shoe model has been selected by the user (see Fig. 2), the system shows the shoe of which the user can visually identify all its components by moving the mouse pointer over and change each one by clicking on it and choosing among a proposed set of elements (shown in the upper-left part of Fig 2). In this way, the user can personalize the shoes in a number of steps, by

Fig. 2. The product configurator NIKEiD from Nike.

changing materials and colors, adding personal ID, choosing among wide and narrow sizes, etc.

The user can also rotate the image, choose among predefined view (e.g., front or side view) and zoom it to highlight details. S/he is always driven throughout the personalization process by the configurator. Feedbacks about the status of the personalization are provided through the function "What's left" that proposes the steps not yet performed. The configuration process ends after all the required steps (twelve in the example of Fig. 2) are performed. After this, the final customized shoe is presented together with the calculated price. The user can save, share (through e-mail or direct link) or order the model. NIKEiD is very easy to be used, it is Web based and it only requires the installation of the Flash player for visualizing the tool.

A limitation of all product configurators is that only predefined changes can be performed by end users, i.e. only those ones that can be performed without changing the manufacturing system and without additional costs for the production chain. There are some cases, like the one reported in Section 4, in which people need to have much more freedom and should be allowed to design themselves the products of interest.

4 The case study

Maiellaro s.r.l. is a company producing classic style furniture. Since this furniture is very expensive, the risk of losing money if it remains unsold is very high. Thus, their business process is different than traditional furniture producers: they only produce those pieces that are ordered by a customer, who looks at the several catalogues the company provides and sends an order of a specific piece. In order to satisfy their customers as much as possible, the company wants to allow all freedom in designing a piece they want, which can be composed of parts chosen by different items in the catalogues and whose dimensions, type of wood and other characteristics are specified by the customers.

Fig. 3 shows a customer request for a personalized bookcase ("libreria" in Italian). The request contains a sketch of the bookcase and indicates references of the articles in Maiellaro's catalogues of which it is composed (e.g. art. 249.70.96) and further personalization requests (like the possibility to have it closed with a glass door). Current practice is that the customers send via fax to the company requests like this one. The company evaluates the feasibility of each request. If it can be satisfied, the price is negotiated through a communication exchange, via phone and/or fax, between company sale office and customer. Once the estimate price has been accepted, the company creates an internal document containing the description of the new piece of furniture and it production starts. This new piece will then be added to the Maiellaro's catalogues.

The Maiellaro's business process provides an interesting solution to the Long Tail problem, being able to satisfy customers desires, still keeping reduced production costs. This case is also very challenging from an ICT point of view [14]. In the next sections we show the approach we have adopted to design a system to be used by company customers to shape their own products.

Fig. 3. An example of request made to Maiellaro company.

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5 Ontology-based approach

One of the problems of the case study presented in the previous section is that currently the information needed to customize a piece of furniture are scattered in different archives. These archives refer to the catalogue of Maiellaro company and to a set of other catalogues of Maiellaro's suppliers. These suppliers' catalogues are very diverse and heterogeneous because they refer to various crafts and arts (e.g. glass suppliers, wood artisans). Thus, it is really difficult to have an overall view on all existing information. Another problem is how to drive customers in selecting components of items in the catalogues and allow them to assemble such components in reasonable ways to create a new piece. We describe here our approach based on the use of ontologies to solve such problems.

First of all, a strategy to connect the objects that constitute the Maiellaro's catalogue with those that belong to the suppliers' catalogues is needed, so that customers can consider all of them as a unique catalogue. The integration of heterogeneous information sources implies the design of a data integration system aimed at dealing with data residing in several sources and at hiding to the user the source of the data s/he is accessing and its structure. The use of ontology for the explication of the knowledge is a possible approach to address such an integration problem. This solution is based on an important requirement for knowledge models: the ability to abstract from the different storage strategies of various catalogues.

Several research projects (e.g., [15], [16], [17]) have led to the definition of ontological models that allow one to describe a given application domain and then to retrieve the associated context information from distributed data sources [18]. Such researches have investigated the use of ontology schemas for modeling implicit and hidden knowledge in order to integrate different databases owned by different providers. For example, in a solution called "virtual approach" [17], [18] data residing at the sources are accessed during query execution, and are not replicated in the integrated system. This approach is adopted in order to use the knowledge base as a sort of semantic access point to the information that can be retrieved from different databases federated by means of an ontology schema. Archives owned by different suppliers can be mapped to each other and related independently from the craft or art to which they refer.

Looking at the literature, we found two cases of ontologies in the furniture context. The first case refers to the transformation of the Arts and Architecture Thesaurus into an ontology in order to capture background knowledge for antique western furniture [19]. In this case, each piece of furniture is considered as a whole and its parts are not described individually. The second case describes a knowledge management design method that aims at supporting designers in reuse of existing design cases [20]. The ontology doesn't describe a piece of furniture in its components but it is used to arrange furniture at "taxology level"; in other words, the ontology is used to help identifying pieces of furniture that can inspire the design of new ones.

For the Maiellaro's case study, an ontology has been defined, to support people customization of pieces of furniture. The customer, starting from furniture shown in the catalogues, is able to identify the combination of components for creating her/his wished piece of furniture. This combination is carried out in terms of substitution or application of components or decorations taken from other pieces of furniture or by means of changes about color, material or size of the components themselves. It should not be presented to the users a classification of all the possible combinations that they can request. On the contrary, customers should be able to combine pieces at their disposal, as they like at best.

The use of the ontology permits to describe the components of each piece of furniture and their properties; for each component, it is possible to specify colors, size, decorations, shapes, and materials. Moreover, the ontology provides all rules and constraints to be applied to assemble various components in order to generate all and only those pieces of furniture that are considered by the ontology. A large set of pieces of furniture is considered in this case study, organized in categories such as tables, desks, bookshelves, armchairs, sofas, wardrobes, consoles, etc. For example, a console is composed by a top, a set of drawers, a set of handles, and a set of legs, as shown in Fig. 4.

Fig. 5 illustrates a portion of the ontology related to the console concept. The classes are used to represent the relations existing among a set of components of a piece of furniture. Solid lines represent relations of subclass. For example: a console is a subclass of a piece of furniture ("mobile" in Italian); its components are: drawers ("cassetti"), legs ("gambe"), top ("piano"), handles ("maniglie") and skeleton ("scheletro"). Dashed lines represent relations of belonging; for example, a console is composed by drawers, legs, top and skeleton; a component is related to concepts such as decoration ("decorazione"), size ("dimensione"), color ("colore") and material ("materiale").

From a technical point of view, the ontology uses a machine-readable format such

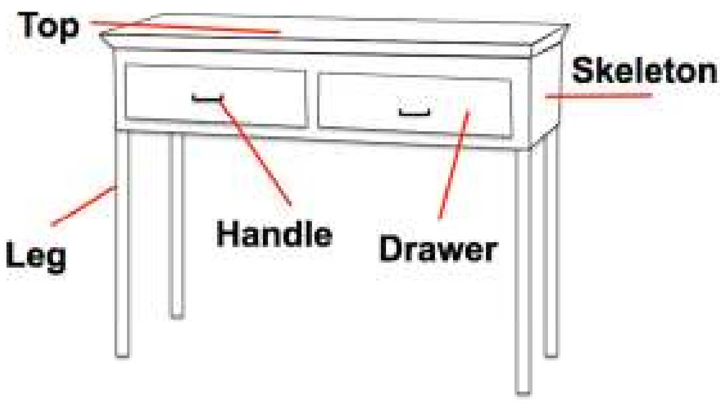

Fig. 4. A console and its components.

Fig. 5. A portion the ontology representing the console concept.

as RDF. Therefore, class names and properties are encoded using RDF labels. Moreover, the mappings between the ontology and the relational schema of each database integrated in the system are encoded in RDF. In order to be able to represent the information mapping, the ontology has been extended by adding two classes: DB_Class_Mapping and DB_Property_Mapping. Because these classes do not model any domain concept, they have been placed outside the original Maiellaro’s class hierarchy. The two classes are endowed with a set of properties, which refer the information related to the mapping between the ontology and each integrated DB. The information mapping inserted in the ontology permits to define transformation algorithms (implemented in JAVA), which translate a semantic query (expressed in SeRQL, an RDF Query Language) into SQL statements, one for each integrated database.

Going beyond standard digital retrieval operations, the system exploits the ontology expressing the concepts relevant for the domain and uses it to integrate the available data sources, providing a uniform point of access to all information. A semantic mediator allows the user to formulate queries in terms of the domain's concepts rather than entities defined in the databases’ logical schemas; e.g., “retrieve all consoles having waxed wooden top” or “retrieve all furniture having decorated drawers”. A query expressed by the user through a form-based interface is mapped onto a semantic query and from this query onto an SQL query. For example, a query to retrieve all consoles made of wood is first translated onto the semantic query:

```
SELECT Consoles
        FROM {Consoles} rdf:type {owl:E22.Man-Made_Object},
              owl:p45f.consists_of {Material};
                       {Material} rdf:type {owl:E57.Material};
                               {Material}rdfs:comment {MaterialName}
        WHERE label(MaterialName) like "wood“
              USING namespace owl = <"http://www.w3.org/2002/07/owl#">
```

and then onto in a set of SQL queries, e.g.:

```
SELECT ConsoleID
        FROM Material JOIN Consoles
                ON Material.Material = Consoles.MaterialID
        WHERE Material.Material=“wood"
```

The obtained SQL statements enable the access to the integrated databases by means of Sesame, an open source semantic Java framework.

The proposed ontology virtually unifies scattered catalogues of different suppliers; it instances a conceptual abstraction of the knowledge developed by experts. Using this system, customers can retrieve data from different catalogues and can combine components in order to create a new piece of furniture; the ontology determines which customer's compositions are acceptable.

6 The developed prototype

In this section, we present the prototype of the system developed for the case study of Maiellaro company, in order to support the negotiation process between customers and the company finalized to order a piece of furniture and, more importantly, to allow customers to create the piece as they wish.

In designing the system prototype, we followed the SSW methodology, which foresees that all the involved stakeholders should actively participate to system design, being provided with suitable software environments, languages and tools to foster their personal and common reasoning about the development of systems that support end users' work [10], [11], [21]. These software environments are called *Software Shaping Workshops* (briefly, SSWs or workshops). The term *workshop* comes from the analogy with an artisan workshop (e.g., smith's workshop), i.e. the workroom where a person finds all and only those tools necessary to carry out her/his activities. Following this analogy, each community of experts participating in the design team, namely software engineers, HCI experts, domain experts, and end users, is provided with a workshop tailored to the experts' culture, through which they contribute to shape software artifacts, i.e. they access and modify the artifacts of interest, and exchange the results of their activities to converge to a common design. Thus, this approach fosters End-User Development and collaboration among all system stakeholders [22], [23]. To permit End-User Development, a new paradigm for the design of interactive systems is considered, called meta-design: professional developers act as meta-designers since, instead of developing the final interactive system, as in traditional design approach, they design software environments for the communities of stakeholders in the design team, who use such environments to collaborate in the whole life-cycle of an interactive system [11], [21], [24].

During the field study we carried out for requirements analysis at Maiellaro company, we found that the design team has to include, together with the professional developers with technical skills, namely software engineers and HCI experts, the following four stakeholders: (a) the managing director, who supervises the company business processes and, in particular, is in charge of the approval of the order of new pieces of furniture, designed by the customers, which will also be inserted in the catalogues; (b) sales office employees, who manage orders by customers in collaboration with the technical office; (c) customers, who order pieces of furniture by selecting items from the Maiellaro's catalogues and customizing them as they wish; (d) technical department employees, who manage technical aspects of new pieces of furniture and also have the responsibility of updating the ontology when new catalogues or new furniture are added.

In the following, we illustrate the workshop devoted to Maiellaro's customers. As described in Section 5, on the basis of the defined ontology, the customer is driven in performing customization activity. Let us suppose the customer Mario Rossi (male) wants to order a console of certain dimensions to fit his living room. He logs into the

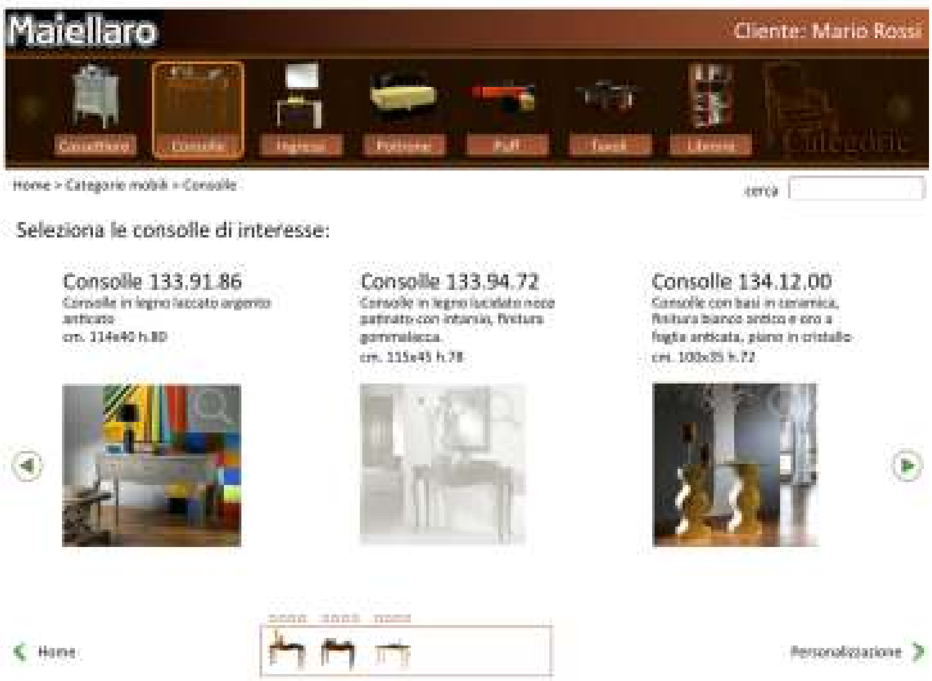

Fig. 6. The customer Mario Rossi browses the catalogue and chooses three consoles of interest.

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system on the Web and accesses the customer workshops. He is informed that he can order a piece of furniture by customizing items in the available catalogues. The customer then goes on to browse the catalogues, where products are organized by category, as shown in Fig. 6. He chooses an item of interest by clicking on its picture, and a thumbnail of that item appears in the box at the bottom of the screen.

When the customer has selected all items of interest, he goes on in creating the piece he wishes. This piece can be either a specific item he found in the catalogue, and for which the customer wants to modify only certain features, such as type of wood, size, etc., or it can be the result of a more sophisticated design process, i.e. the composition of parts taken from different items. For example, he would desire a console with parts taken from the selected items in the box at the bottom. He goes on with his customization process by clicking on the link at the bottom right of Fig. 6 “Personalizza”; a new screen appears where he can indicate the component of interest in each of the console previously selected. By clicking on the third thumbnail at the bottom, the picture of that console appears (console number 134.03.87), as shown in Fig.7. On the basis of the ontology (see Fig. 5), the system shows that, for console, the components that can be selected are: top (“piano”), leg (“gamba”), handler (“maniglia”), drawer (“cassetto”), skeleton (“scheletro”). The customer selects a component by clicking on the checkbox at left. In Fig. 7, Mario Rossi has selected the top of console n. 134.03.87. For this component, he can also specify material, color,

Fig. 7. The customer is composing the console he wants to order and has chosen the top from the console number 134.03.87.

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size, etc. by clicking on the button at right of the label “piano”. A pop-up window appears at the center of the screen (it is not shown in Fig. 7) and the customer specifies the values he wants. At the right part of Fig. 7, a summary of the selected components and the indication of the console from which each specific component comes is shown. In the example, only the top from the console n. 134.03.87 has been selected. The customers can go on selecting the remaining components from the same console, or he can click on another item in the box at the bottom of the screen, so that it will appear at the main area of the screen and the customer will select other components from it. The customer can also go back, clicking on “Categorie mobile” link, and choose other consoles, which will be added in the box of selected items.

At any moment, the customer can visualize his overall composition by clicking on the link “Riepilogo” at the screen bottom right and the screen in Fig 8 appears. It shows the catalogue items from which components that contribute to create the console the customers wants come from. Moreover, for each component the features specified by the customer, e.g., material, size, etc., are indicated. Once the user has completed the console s/he wants, a click on the link “Ordine” at the screen bottom right in Fig. 8 sends the order to the sales office, which checks the design created by the customer The customer can then better see the overall design of the console s/he specified. Once sales office and customer agree on the price, the official order is delivered and the production of the new console starts.

As we said, other system stakeholders are the technical office employees, who are in charge of adding new catalogues provided by different suppliers in order to map them on the ontology, independently from their location and typology. To this aim, they have to handle the information retrieved from different databases as instances of

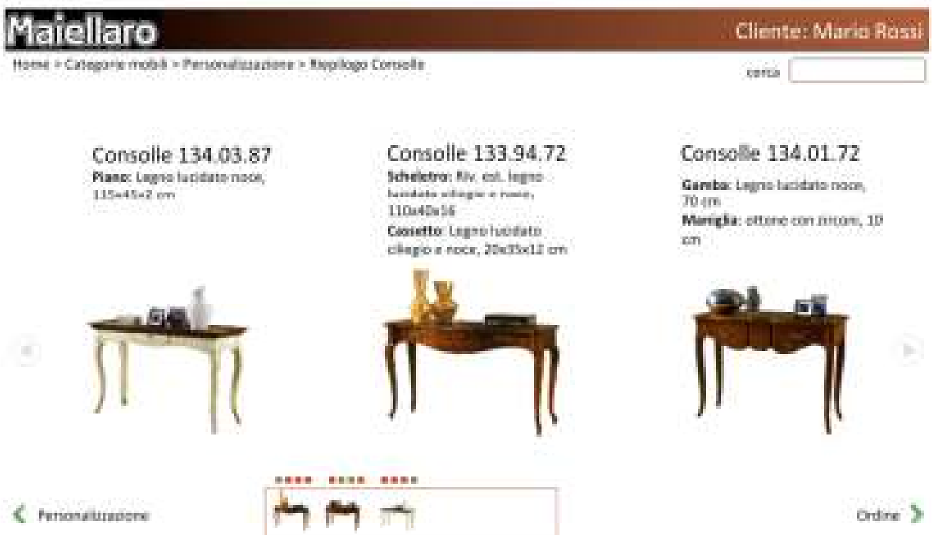

Fig. 8. Summary of console components chosen by customer Mario Rossi.

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the ontology classes and to establish a correspondence between the relations defined in the database schema and the classes in the ontology. The result of this process, iterated for each catalogue, is a semantic network able to translate the DB schemas onto concepts and relations of the ontology. The information defining the mappings is used by the system to generate SQL code for querying each DB schema. In this way, the query can be expressed independently from the query languages of the underlying database. Currently, this activity is carried out by using Protégé [25]. We are developing a new software environment to support the mapping process through a wizard that drives the user along the appropriate steps.

7 Conclusion and future work

This paper has proposed a new approach to product customization, in order to give people more freedom in creating products that best fit their needs and desires. The motivation came from the Maiellaro s.r.l. company, which produces classic style furniture. Their business process is very different than traditional furniture producers, since they focus on niches of products rather than on mass production. In order to satisfy its customers as much as possible and to avoid producing furniture that might remain unsold, the company creates only pieces of furniture which are ordered by customers, who look at the company catalogues and design each piece of furniture they want, which may be composed by parts chosen from different items in the catalogues, and assembled together.

The system described in this paper for the Maiellaro case study allows customers much more freedom in customizing products than current product configurators, thanks to the use of an ontology that models the possible compositions of different parts in a whole piece, thus driving customers' design activities and ensuring that they may only perform acceptable modifications. A prototype of the system is described, which shows how customers can express their requests in order to create the furniture piece they wish and how they can, together with the company, finalize its order. This prototype has been recently developed and only formative evaluation has been performed so far, primarily with inspection methods and user testing through a thinking aloud method, involving four people. More accurate studies will be performed in the near future.

The proposed solution can be applied to different types of products, e.g., assembled computers, shoes, etc. It exploits the definition of a comprehensive knowledge base able to integrate heterogeneous data-sources and to contextualize their information with the active participation of domain experts.

A new possible research direction could address the study of an access control model based on the notion of group-based data sharing to apply to the ontology. Another research direction could be related to the use of the ontology for integrating data sources other than relational databases. In particular, a relevant direction is to use the ontology in order to support a semantic orchestration of web-services. In this scenario, the data sources are accessed using specific web services and the

Maiellario's system is used for coordinating them according to the conceptual ontology.

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