

A web-based platform for customer integration in the decentralised manufacturing of personalised products

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Abstract

In today's highly customer-oriented market, web-based approaches are the main enablers towards achieving a sufficient level of customer involvement during the design phase of new products. This research work, describes a novel software architecture that facilitates the ability to visualize and manipulate three-dimensional product design parameters under constraints. The manipulation is performed in real-time, over web, comprising Virtual and Augmented Reality functionalities. The approach integrates the customer into the supply chain of the personalised product manufacturing, as the design changes have a direct impact on the supply chain configuration. The software architecture and the description of the offered functionalities are presented, as well as the implementation tools and programming frameworks. The approach is tested on a case study from the automotive sector.

Keywords: Personalisation, 3D modelling, Web technologies

1 INTRODUCTION

The customers in today's globalised market express the need for truly unique products. A tendency towards larger individualisation is evident. The customer requirements must be efficiently identified and sufficiently satisfied. The customer therefore, has to be treated as an individual and not merely as a market segment [1]. The quote from Henry Ford: "Any customer can have a car painted any colour that he wants as long as it is black" [2] is no longer valid. The main idea behind product personalisation is to successfully integrate the customers into the design of their own products [3]. This integration can be achieved during the selection and configuration of an existing product. The design changes performed by the customers, must be fulfilled by the OEM. The OEM has to configure the supply chain in order to carry out the production of the personalised product. In addition, product personalisation by the customer can be valuable for realistic identification of a desirable future product. Product customization is no longer a buzzword; instead it is a common practice, which is realised currently in almost every market domain. In order to support the design of new products, the end users should be tightly integrated in the design process. Through their involvement, useful information can be extracted from the manufacturers [4]. The purpose of this research work is the development of methods towards integrating the customers into the design phase of personalised products. Thus, the customers become active participants in the configuration of the supply chain.

2 STATE OF THE ART

The globalisation of the markets that came along with technological innovations, reshaped the value added chain in the global manufacturing network. Chrystolouris stated in 2004: "It is increasingly evident that the era of mass production is being replaced by the era of market niches. The key to creating products that can meet the demands of a diversified customer base is a short development cycle, yielding low cost and high quality goods in sufficient quantity to meet the demand" [5]. A transition is on-going from a Build-To-Stock (BTS) to a

Build-To-Order (BTO) paradigm. In a BTS system, products are fabricated according to demand forecasts for an anonymous mass market. In a BTO system however, products are only built in response to an actual customer order. This, demands a large number of adjustments in marketing, production and logistics [6]. Assembling directly on order, on the other hand, reduces the risk of loss due to obsolescence. Completed products will become obsolete faster than their components. Thus, there is a definite advantage in not assembling before the customer has actually ordered a product. Delayed differentiation can allow the production of some standard components, while the customer specific features and components can be added as late as possible [7].

The evolution of the Internet and software technologies, enabled the means for market and economic globalization [5]. The Internet improved the coordination process inside the manufacturing networks [8]. The advent of the World Wide Web (WWW) revolutionized the market scene. During the last fifteen years the number of online purchases has increased. The retailers, in almost every industrial sector, offer their products online, offering the customers a wide variety of variants. Recent surveys show, that 89% of the buyers prefer shopping online to in-store shopping [9]. Following that, consumers around the globe expressed the need for unique products that combine quality and short life-cycles, which are also available at low prices, at the right time [10]. Web-based and e-Commerce systems have been implemented, and have proved to be very effective in capturing the pulse of the market [1]. The online competition among companies, results at further and rapid evolution of web technologies. Web-based toolkits for mass customization purposes are deployed, which aim at providing a set of user-friendly design tools that allow trial-and-error experimentation processes, and deliver immediate simulated feedback on the outcome of design ideas. Once a satisfactory design is found, the product specifications can be transferred into the firm's production system, and the custom product is subsequently produced and delivered to the customer [12]. Variety can be achieved at different stages of a product lifecycle. It can be realised during design,

fabrication, assembly, at the stage of sales, and through adjustments at the usage phase. Moreover, variety can be realised during the fabrication process e.g. through machining, or rapid prototyping [11]. Potential solutions in order to achieve mass customization, including changes in the product design and manufacturing process, have been proposed [13]. Nowadays even more design and assembly work is conducted in terms of collaborative projects across globally distributed design teams, companies and software modules. Proposed approaches include e-Assembly systems for collaborative assembly representation [14] and web-based collaboration systems [15]. The research in this area although, needs to be expanded in order to provide tools for assembly representation and product variant customization. The reason is that globalized design and manufacturing often require the variants for local markets to be generated by regional design teams, which use different assembly software and supply bases [7]. A web-based integrated platform was presented by Mavrikios et al. in 2011, called Collaborative Prototype Designer (CPD). The CPD has

been developed to support the collaborative product design activities. It allowed real-time collaboration among geographically dispersed user groups during product design activities [16]. A web-based workflow system, focused on the initial design and engineering of a production system, was proposed in 2011 [17].

3 MODEL OF USER INTEGRATION IN PERSONALISED PRODUCT DESIGN

The user adaptation procedure aims at enabling the integration of a variety of users to the platform. The read/write privileges and the layout and functionalities of the interfaces, differ according to the role of the end user. OEMs have access to interfaces that comprise advanced content, whereas customers are offered user-friendly interfaces with straightforward controls. The first goal is to effectively integrate the customers in the initial design, making them a part of the supply chain. In addition, a main goal is to support the collaboration and communication between OEMs, suppliers and sales representatives.

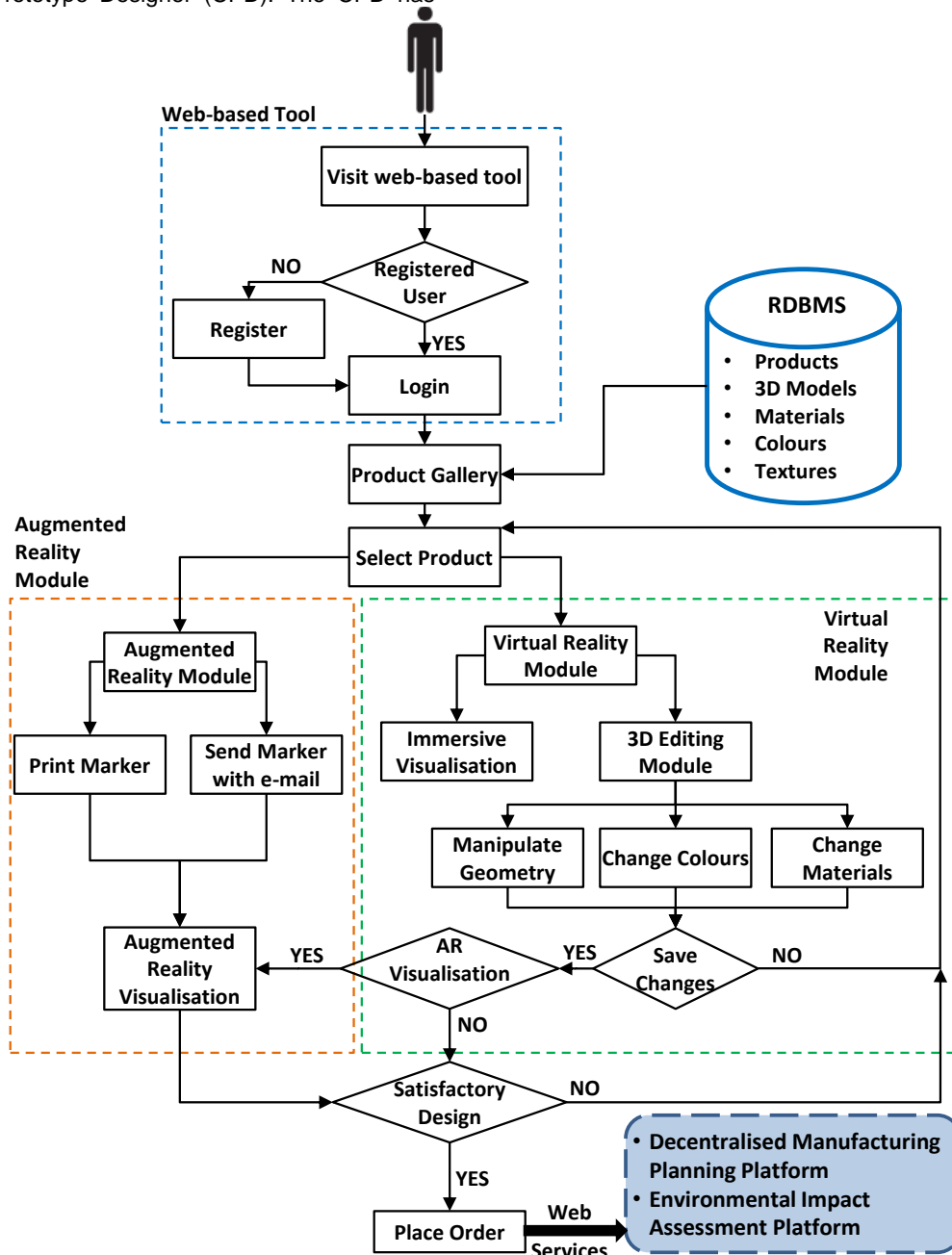


Figure 1. Virtual and Augmented Reality Tool Workflow - Connection with Decentralised Manufacturing Planning Platform and Environmental Impact Assessment Platform

The typical scenario of the system's functionality is described below, and in Figure 1 above. The customer registers and logs in to the web-based platform. A product gallery is presented, and the customer browses through the available designs of the product. Once a specific product is selected, the customer is provided with the ability to personalise it. The personalisation can be performed utilising a web-based 3D configurator. Each product allows for different modifications, pre-defined by the OEM. The allowed design modifications are strictly defined to ensure manufacturability, branding and availability constraints. Modifications may include colour selection, material and texture selection, choice of additional features, and geometric modifications. Moreover, the Augmented Reality tool is provided as an advanced visualisation means. Once a satisfactory design modification has been performed, the customer may place it as an order. The design is tested in real-time for eligibility (geometry constraints, availability of materials etc.). The customer needs, expressed through the customized product, must be fulfilled by the OEMs in a cost-efficient, fast and environmentally friendly way. An integrated platform, namely the Decentralised Manufacturing Planning Platform is responsible for processing the order details. Based on the customisation, customised Bill of Materials (BoM) and alternative Bill of Processes (BoP) are automatically generated. Moreover, the integrated Environmental Impact Assessment Platform, simulates the production and transportation schemes and calculates the environmental indicators Figure 2. The calculated indicators include abiotic depletion acidification, eutrophication, global warming, ozone layer depletion, human toxicity, fresh water aquatic eco-toxicity, marine aquatic eco-toxicity, terrestrial eco-toxicity and photochemical oxidation. Through a multi-criteria decision-making process, the module evaluates the feasible alternative network configurations for carrying out the customised order. The supply network is configured according to an evaluation that takes into consideration production cost, lead time, quality, and environmental impact [18].

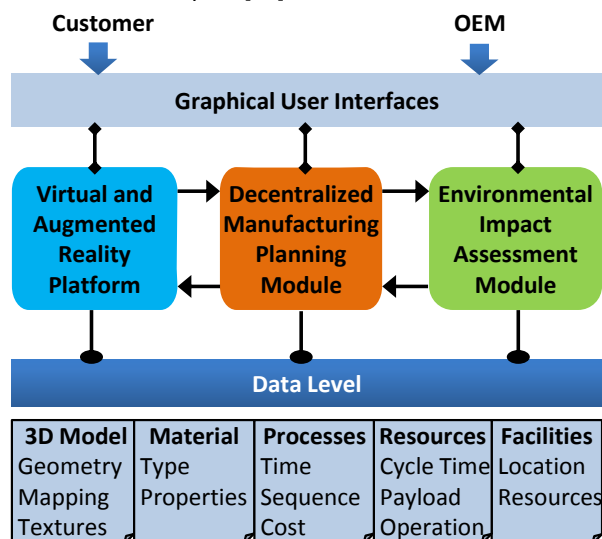


Figure 2. Architecture of the web-based platform and communication between the modules

4 WEB-BASED VIRTUAL AND AUGMENTED REALITY PLATFORM FUNCTIONALITIES

A basic component of the Augmented Reality (AR) and Virtual Reality (VR) modules, is the 3D visualisation engine. The visualisation panel utilises the *JPanel* class. *JPanel* is a general purpose container for web-based

applications. It enables 3D visualisation over web, and can be embedded within typical web-based applications.

4.1 Constraint-based 3D Editing Module

The virtual reality platform comprises immersive visualisation and 3D editing features. The aim is to enhance the customer perception towards the product, integrate him in its initial design.

Constrained-based 3D modelling is widely used nowadays for parametric design. The geometry of the model is represented by a constrained parametric model. The constraints are imposed on the elements of the model, such as on edges, vertices and faces. A geometric constrained problem can be defined by a set of constraints $C=\{c_1, c_2, \dots, c_{nc}\}$ that are imposed over a set of points $P=\{p_1, p_2, \dots, p_{np}\}$ [19]. An extended survey on constraint-based approaches is presented in [20]. The constraints used in the presented research work are defined due to manufacturability, branding and availability reasons. The customers may modify the geometry in predefined ways, so that the result can be actually produced by the manufacturer. The constraints include: fixed parallel dislocation of related edges, fixed points that cannot be moved at the contours, maximum and minimum length of lines and maximum and minimum angles for arcs.

The web-based platform comprises a gallery of purchasable products that can be modified by the customers. Upon selecting the desired product, the 3D editing platform visualises the standard product model. The web-based editing tool, comprises a user-friendly interface with straightforward controls. The customer is not assumed to possess any advanced CAD (Computer Aided Design) modification knowledge. Therefore, sliders, radio-buttons and a colour palette are offered, for minimizing the error possibility. The 3D modifications are enabled by a customised version of the JavaView applet. JavaView is a free and open-source library that exposes an API. It allows for interactive 3D geometry modification and visualisation [21]. The viewer of JavaView supports interaction features of an advanced 3D editing tool. Indicative functionalities include [22]:

- Rotation, panning, zoom, camera control, picking
- Inspection of geometries and material properties
- Selective display of vertices, edges, faces and vector fields
- Animations, key frames and auto-rotation
- Subdivision and simplification of meshes
- Adaptive and hierarchical triangulations
- Advanced visualisation algorithms and textured surfaces
- Import and export of geometries in multiple data formats (OBJ, STL, VRML etc.)

The JavaView applet is displayed in Figure 3 below [21]. Based on this software version, a series of modification and interface customisation has been performed, in order to develop additional functionalities and improve the user-friendliness.

The functionalities offered by the 3D editing module are:

- Selection of product components (e.g. hood, door)
- Pan, Zoom, Rotate and Scale
- Selection of individual vertex or of groups of vertices
- Selection of individual faces or of groups of faces
- Manipulation of individual vertices or groups of vertices
- Manipulation of individual faces or of groups of faces
- Selection of colours, materials and textures

Moreover, the design changes can be saved for Augmented Reality visualisation or future use (e.g. Rapid

Prototyping purposes). The tool can export the modified model into the following commonly-used file formats: OBJ, STL, DAE and VRML.

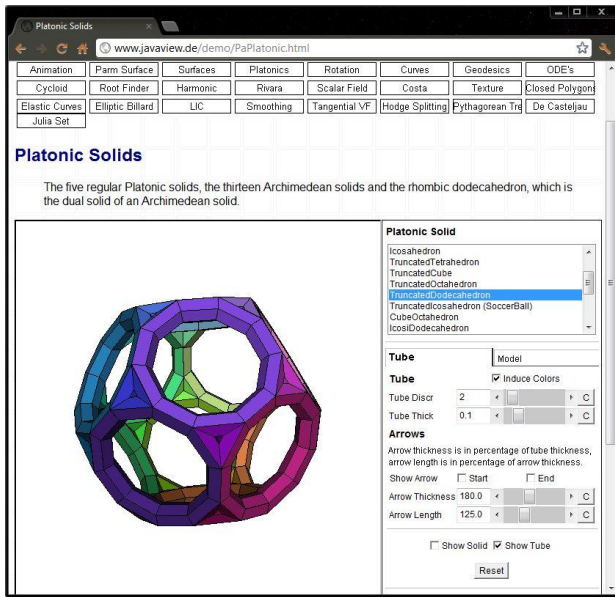


Figure 3. JavaView Sample for the visualisation and editing of a truncated dodecahedron

4.2 Immersive Visualisation

The customer upon performing the desired design changes (personalising the product), is given the ability to download the modified 3D model on a PC. The 3D model can be exported in a variety of standardised file formats, such as .dae, .obj and .wrl. Immersive visualisation, however, requires specialised equipment, such as VR helmet, glasses, gloves and specialised software. The OEM provides Virtual Reality platforms at specific sites. A number of dealers are also equipped with immersive and interactive visualisation platforms. The customer visits these sites and visualises the product in an immersive environment. Moreover, the interactive visualisation platform allows for the 3D manipulation of the product. The customer is able to perform design changes using specialised gloves, and visualises the changes in real-time.

4.3 Rapid Prototyping

VR technology can be valuable for the design of products, which are considered complicated and that their experimental testing or verification may be cost and/or time consuming [26]. An additional functionality of the presented approach is the ability for generation of Rapid Prototyping (RP) models. The tool provides the capability to export the customised product to an STL file format [27]. The STL data can be transferred to a 3D printer, in order to produce a physical mock-up of the customised product. Therefore, the design phase can be shortened by the development of rapid manufacturing models. The production of RP models can be realised by additive manufacturing methods, such as layered printing. Moreover, the RP functionality can be utilised for marketing reasons. The personalised product can be printed into a physical mock-up by affordable 3D printers [23].

4.4 Augmented Reality Visualization

The Augmented Reality (AR) technology is mainly the superimposing of virtual elements / artificial information onto the user's view of the real world. AR can be used to enhance the users' perception towards a product design [24] among others. The AR module allows real-time

visualisation of the personalised product geometry and appearance over web, using a computer screen. The AR module communicates with the 3D editing module. The design changes performed by a customer, are stored in a database as part revisions (compared to the standard version of the product). The stored product design can be retrieved in order to be used by the AR module. Moreover, the customer is provided with the ability to print the AR marker and visualize the product at their computer screen, using just a webcam. An AR marker generator is embedded within the tool, and each marker is mapped to a specific 3D model, and to specific functionalities. One marker is used for visualising the 3D model, and a different one is used for auto-rotating the model over a still marker.

The implementation of the AR module was based on a combination of free, and open-source libraries. The developing environment was the JAVA™ platform. Moreover, the visualisation of the 3D model was achieved using the Java3D library. The position tracking of the AR marker, and the manipulation of the AR scene is performed by utilising functionalities from the NyARToolkit [25].

The software workflow of the augmented reality module is as follows (also depicted in Figure 4):

1. Capture video streaming from the camera
2. Search for augmented reality markers
3. Identify markers, their position and orientation
4. Apply positions and orientation to 3D models
5. Render the 3D models on top of video frame and visualise augmented content on screen

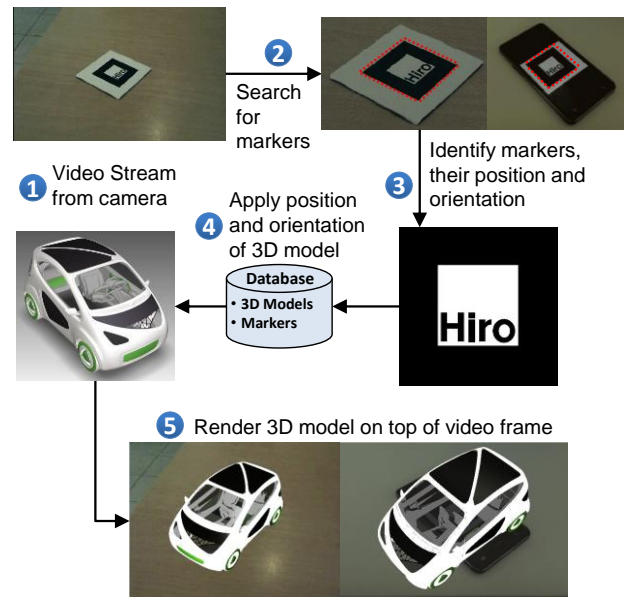


Figure 4. Workflow of Augmented Reality Module

The libraries of NyARToolkit, utilise computer vision algorithms to solve the problem of the relative camera position. The video tracking libraries calculate the real camera position and orientation relative to physical markers, in real time. The tracking is based on a basic corner detection approach with a fast pose estimation algorithm (Figure 5).

The relationship between the coordinates of the marker and the camera coordinates, is calculated by image analysis. The relative rotation and translation of the marker, and the camera, are calculated in the following matrix (1):

$$\begin{bmatrix} X_C \\ Y_C \\ Z_C \\ 1 \end{bmatrix} = \begin{bmatrix} R_{11} & R_{12} & R_{13} & T_1 \\ R_{21} & R_{22} & R_{23} & T_2 \\ R_{31} & R_{32} & R_{33} & T_3 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X_M \\ Y_M \\ Z_M \\ 1 \end{bmatrix} = T_{CM} \begin{bmatrix} X_M \\ Y_M \\ Z_M \\ 1 \end{bmatrix} \quad (1)$$

The perspective projection of the ideal screen by the camera is performed in the following matrix (2):

$$\begin{bmatrix} hX_I \\ hY_I \\ h \\ 1 \end{bmatrix} = \begin{bmatrix} sf_x & 0 & x_c & 0 \\ 0 & sf_y & y_c & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X_C \\ Y_C \\ Z_C \\ 1 \end{bmatrix} = C \begin{bmatrix} X_C \\ Y_C \\ Z_C \\ 1 \end{bmatrix} \quad (2)$$

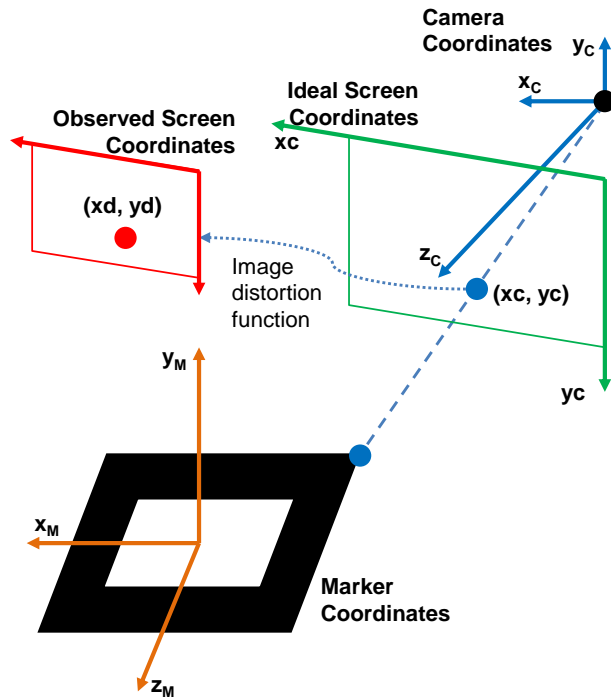


Figure 5. Augmented Reality Computer Vision Coordinate System

The lights that illuminate the scene, so that reflections on colour and materials can occur are three: one ambient light and two directional. A background node displays the current video frame. An instance of a branch group and behaviour is created for the car. The behaviour and *BranchGroups* (BG nodes in Figure 6) are triggered by the *MarkerBehavior* class 30 times per second. The breakdown of the augmented reality module architecture is presented in Figure 6.

The *MarkerBehavior* changes the image in the background node to be the current video frame, and updates the position and orientation of the models so they stay on top of their respective markers. The *DetectMarkers* object, which maintains a list of *MarkerModel* objects and a detector that finds the markers in the camera's captured image. A marker position is used to move its corresponding model via a *TransformGroup* (TG nodes in Figure 6). Each *MarkerModel* object, holds marker information and builds the Java3D scene graph for its associated model. The models are loaded using the *PropManager* class. It utilizes the NCSA Portfolio library, so the models can be defined in a range of different 3D formats. The transforms applied to the models tend to make them 'jitter', due to slight variations in their calculated rotations and positions from frame to frame.

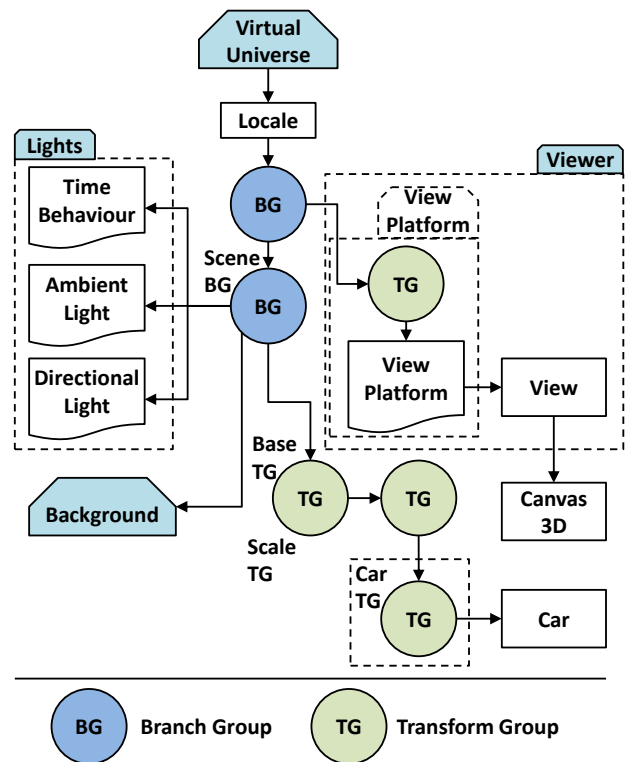


Figure 6. Augmented Reality Module - Software Components

5 SOFTWARE ARCHITECTURE AND IMPLEMENTATION

The software design was performed using UML diagrams, developed in IBM's Rational Architect v8.0.2 with UML 2.3 standards. Further to that, the programming of the platform, the testing and debugging is accomplished using Eclipse J2EE v3.6 (Helios). The business logic of the proposed platform is contained in the application server of the system. The Apache™ Tomcat v7.0 is used as a webserver and servlet container. The Relational Database Management System (RDBMS) used was Oracle 9i, provided by Oracle.

The deployment of the Virtual and Augmented Reality modules is based on a Service-oriented Architecture (SoA). This ensures the scalability of the separate modules and their seamless interoperability. The development of the software tools was performed using the Model-View-Controller (MVC) architectural pattern. MVC separates the implementation concerns and makes the development scalable, maintainable and capable of increased design complexity. Figure 7, contains the basic classes and interfaces, upon which the software implementation was based. A three tier architecture was implemented, that comprises the layers: Presentation, Business and Data. The presentation layer is where the user interface is dynamically generated. Most of the page display and navigation activities are handled by the Java Server Pages (JSP) technology, whereas a web browser renders the HTML code. The presentation layer communicates with the data layer through the business layer. The business layer handles the information exchange between the database and the presentation. Inside the business layer, the objects are modelled and their communication is specified. Finally, the data layer is used to connect the application to the database, to make queries and to return query results. The structure of the service layer is developed in accordance to the MVC pattern. The services are the communication layer between the presentation layer and the persistence layer.

The Hibernate framework, which is an object-relational mapping (ORM) library for the Java programming framework, provides the ability for mapping the object-oriented domain model to a relational database.

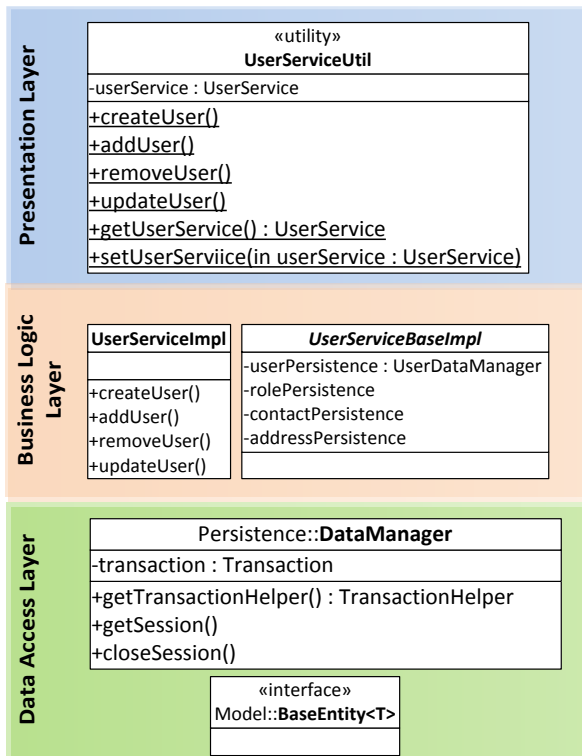


Figure 7. Three Tier Architecture of the Web-based Platform

6 DECENTRALISED MANUFACTURING PLANNING PLATFORM

The geometric modifications performed by the customer, alter the product specifications. The modified dimensions of the product may require different production setups.

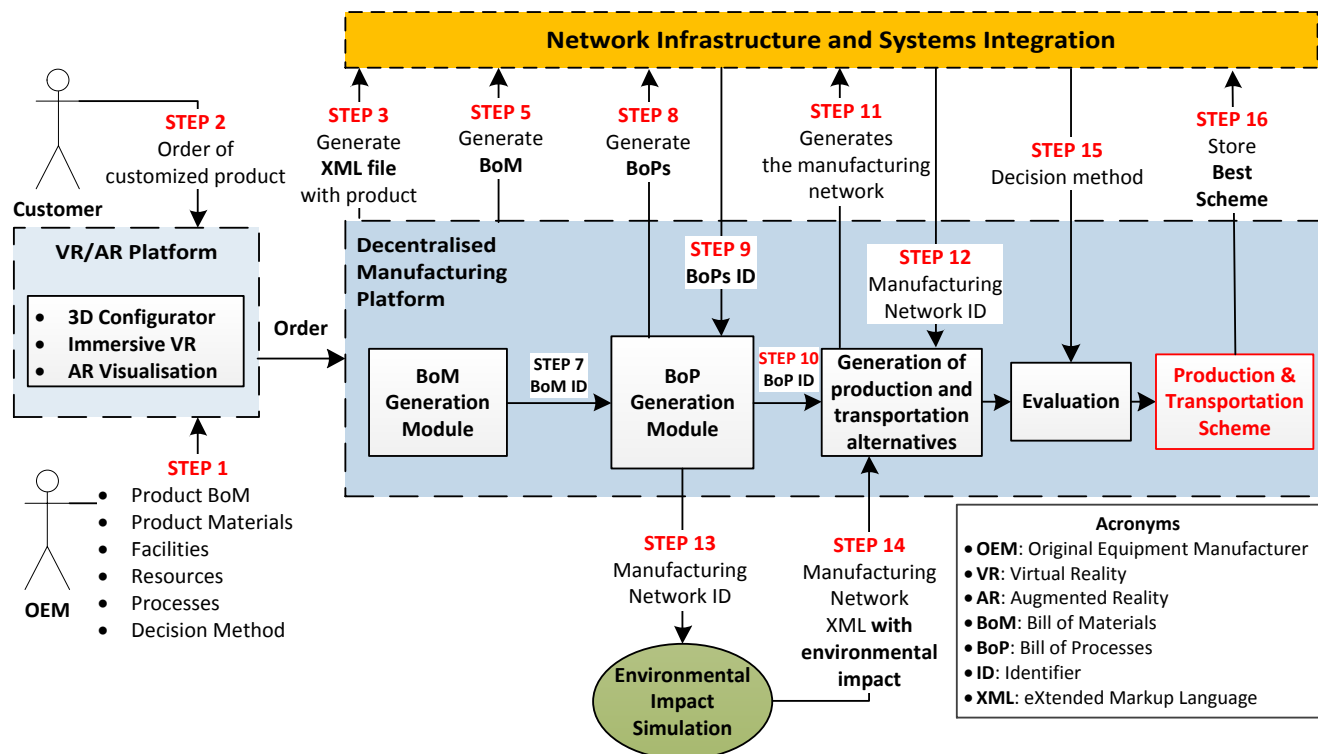


Figure 8. Workflow of the VR/AR Platform and connection with the Decentralised Manufacturing Planning Platform and Environmental Impact Assessment Platform through the Network Infrastructure and Systems Integration

Moreover, the weight of the parts that need manufacturing is modified. To support the configuration of the supply chain for the production of the personalised product, the integrated Decentralised Manufacturing Planning Platform is utilised. The Decentralised Manufacturing Planning Platform utilises a multi-criteria decision making approach, for the identification of efficient production and transportation network configurations.

For each personalised product, a customised Bill of Materials (BoM) is generated. The generation of BoM is performed by parsing the 3D file. The modifications/deviations from the standard version of the product are identified inside the personalised 3D model. The BoM is formalised in an XML scheme, in a tree structure containing detailed information about the product. The BoM contains the geometric characteristics of the personalised parts of the product, in the form of vertex coordinates. Moreover, it describes the materials and textures selected for all the product components. The colour is represented in RGB values (Red Green Blue). The volume and weight of each part is also listed. Finally, the quantity of the required components is included. The customised BoM is afterwards mapped into alternative Bill of Processes (BoP). The alternative BoPs include alternative processes for manufacturing and transporting the components of the product over the network. Based on the BoP the tool retrieves from the database the resources (machines) that are capable of producing the components. The OEM performs the data entry through user-friendly interfaces. The required data entry includes the products and their details and 3D models. Moreover, the OEM inserts the resources and their characteristics, such as cycle time, Mean Time Between Failures (MTBF), Mean Time To Repair (MTTR), payload and production cost per time unit.

The resources belong to different OEM plants, suppliers and dealers. The stakeholders of the supply chain, possess different resources and are located in dispersed facilities. The tool forms the feasible alternative production and transportation schemes. Each alternative comprises a network configuration, that is capable of producing the personalised product. The alternatives are evaluated using a multi-criteria decision making method. The criteria are user-defined and include cost, time, CO₂ emissions, energy consumption and quality. The selection of the most preferable network configuration, is based on the utility values of the alternatives (Figure 8).

The selection of the preferable alternative scheme can be performed using exhaustive or intelligent search methods. During the exhaustive search method, all alternatives are generated and evaluated. The exhaustive search gives as output the best alternative with respect to the selected criteria weight factors. The intelligent search algorithm uses three adjustable control parameters. The Maximum Number of Alternatives (MNA) controls the breadth of the search, and the Decision Horizon (DH) controls the depth. The Sampling Rate (SR) guides the search through the solution space [28].

7 AUTOMOTIVE PILOT CASE

A real-life industrial scenario was used to demonstrate the functionality of the tool, utilizing data from a European automotive manufacturer. The scenario involves the design and production of a customized car. In Figure 9 below, the 3D model of the car of the pilot case is loaded in the 3D editing module. Moreover, a set of vertices are selected (purple coloured dots on the front bumper). The figure below (Figure 9), is an outcome of the product personalisation by a customer. The front bumper has been modified according to the needs of the specific customer.

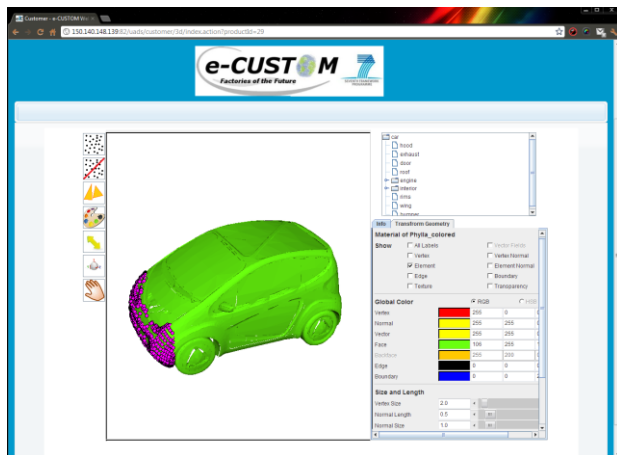


Figure 9. Visualisation and Editing of the 3D car model – 3D Editing module

The Augmented Reality module provides the capability to send the marker via email to the customer. Upon providing a valid e-mail address, the customer can receive an automated e-mail from the System Administrator, with the marker enclosed in a PDF file. Further to that, the link "Print AR Marker" provides the ability to print the marker. The module accesses the connected printer devices, and prints the marker upon customer confirmation. The application of the Augmented Reality module to the automotive pilot case, is depicted in Figure 10. The visualised product is at first personalised by the customer in the 3D editing module (selection of materials for the roof, change of colour to the rims and modify the pattern and size of the air inlet).

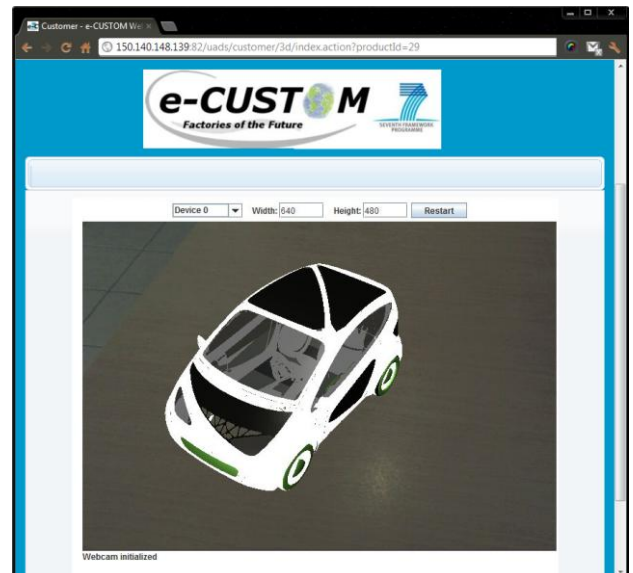


Figure 10. Reality Visualisation of the 3D car model - Augmented Reality module

8 CONCLUSIONS AND FUTURE WORK

The presented Virtual and Augmented Reality platform, allows the integration of the customers into the design phase of personalised products. The customer becomes a part of the supply chain, because the design changes directly impact the configuration of the production and transportation network. Moreover, the modular software architecture enables the adaptation, scalability of the platform. Furthermore, it allows the seamless integration with legacy tools. The platform can exchange data through XML, coming from Enterprise Resource Planning (ERP) packages.

Future work will focus on extending the capabilities of the platform. Additional 3D modification functionalities will be developed, such as parametric design and solid modelling. A reasoning mechanism will be developed, that will identify similarities in past projects and thus, shorten the required computation time. A Case-Based Reasoning (CBR) mechanism will be developed and integrated into the platform, for enabling this functionality.

Moreover, a manufacturability evaluation mechanism will be developed in the 3D editing module. The modified geometric characteristics will be identified, and the mechanism will assess the feasibility of the design to be manufactured.

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