New technologies for customizing products for people with special necessities. Project FASHION-ABLE

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Mass-customization of wearable products are offered as a higher added value to the broad public and have to compete with ready-to-wear offer. However, people with specific requirements are not covered by the current mass-customized products. This is the case of the elderly, disabled, diabetic and obese population groups when wearing textiles, clothing, footwear and textile-based orthotic goods. Further, at present, available knowledge and flexibility of production equipment and machinery of SMEs operating in these traditional industries (even those that already offer made-to-measure products to the mass public) is unable to respond to the individual needs among such heterogeneous groups. The FASHION-ABLE project has solved this problem with a comprehensive set of solutions.

Keywords: ADVANCED MANUFACTURING TECHNOLOGY, AUTOMATED, MANUFACTURING SYSTEMS, CAD/CAM

1 Introduction

Mass customization offers an added-value to the consumers. But the current products are manufactured for mainstream consumers. Consumers with special needs (e.g. disabled people) have problems to find garments and shoes adapted to their necessities. While customization is an added-value for mainstream consumers, for people with special necessities the customization is a real need. The FASHION-ABLE project aims to provide technology to enable the agile and eco-efficient production of personalised products in terms of health and performance, addressing the complex individualised needs of such growing market niches out of the scope of mass-produced goods. In particular, the FASHION-ABLE has selected three products for three highly challenging target groups: fashionable footwear for diabetic feet, fashionable clothing for wheelchair users, high-performing textile compression bandages for obese people.

Customization of shoes is a necessity for people with diabetic feet. Today in Europe, there are 60 million diabetic sufferers (as of September 15, 2014, World Health Organization listed on its website), and over half develop diabetic feet (30 million). Therefore, diabetic feet could be an important market for European shoe manufacturers.

Something similar happens with overweight people. The prevalence of pain and acute periods of musculoskeletal disorders (Bevan et al. 2009) increases with age and weight. There is good evidence to support the use of some braces and bandages (Gravlee and Van Durme 2007) in order to improve physical function, slow disease progression, and diminish pain. However, the people with overweight have problems to purchase comfortable low-back braces adapted to their anthropometry.

Wheelchair users are an important niche market in Europe: 7-8 million (1% of European population), as of January 19, 2015, RehaDesign listed on its website. Wheelchair users are a highly heterogeneous population group which locomotion mean imposes a permanent posture different from standing causing that contact areas bear body weight during long periods. The lack of muscle tone and activity reduces natural body cushioning and makes their circulatory system less efficient. The lack of sensory feedback makes comfort problems unnoticeable and their skin tissue especially vulnerable. Prolonged contact periods and skin folds due to static sitting posture increase sweat. Physiological disorders also contribute to favouring moisture and hygienic problems (e.g. urine catheter losses). Due to all these reasons they have a real need of adapted clothes.

The aim of this paper is to introduce the methodology developed and to present some of the results obtained in order to demonstrate that the methodology is feasible.

2 Methodology

The methodology followed consists of three main phases: (I) Definition of the end-user product specifications and SMEs needs. (II) Definition of a new customised product development framework that connects costumers with manufacturers. (III) And create new manufacturing tools to link the end-user needs with the product.

2.1 Definition of the end-user product specifications and SMEs needs

This phase is at the core of the project and sets the knowledge foundations by defining the specifications and requirements of the new customization technologies for the targeted population groups. It is the core around which the development of technology has been built.

Specifically, information from health professionals and users has been gathered in two main dimensions, which are:

- User needs and requirements (from a professional´s and from a user´s point of view). For this, semi-structured interviews (Olabuénaga 2012) and focus groups (Bruseberg and McDonagh-Philp 2002) are used to gather information from doctors, orthotists and end-users. Five focus groups have been done with end-users and experts (doctors and orthotists).
- Anthropometric information. The anthropometrical dimensions are related with fitting problems using fitting tests developed during the project. Two different approaches are applied:
    - Clothes and textile orthotics. Morphotypes and anthropometric dimensions are related (Vinué et al. 2014) with product dimensions using regression logistic models.

- Footwear. In this case the morphotype approach is not possible because some customers suffer amputations and big deformations. For this reason, the correct approach is to design the last using a 3D model of the foot.

While the user requirements were used to develop the configuration space of the individualized products, the anthropometric information was used to select those measures relevant to influence the shape (and thus the pattern) of individualized products.

As an example, in the following it is described in detail the methodology applied to textile orthotics in order to select the more relevant anthropometric measures. A similar procedure was used for the rest of textile products.

(1) Pre-selection of measures to be included in the statistical models based on previous research (Alemany et al. 2013) and the opinion of the experts.

(2) Selection of current products and sizes in the market with the help of the experts: 4 types x 5 sizes = 20 lumbosacral orthoses

(3) Selection of subjects: 6 women and 8 men, in order to cover 3 factors:

  (a) Height: short and tall

  (b) BMI (Body Mass Index): less than 25, more than 31

  (c) Age: Middle-aged (40 to 55) and elderly (more than 65.)

Table 1: Distribution of subjects

Sex	Age	Age group	Height(cm)	BMI
M	68	Elderly	158	29.6
M	70	Elderly	159	25.3
M	66	Elderly	166	26.4
M	71	Elderly	174	33.6
M	42	Middle	167	22.2
M	50	Middle	170	29.4
M	48	Middle	180	26.0
M	53	Middle	181	34.1
W	71	Elderly	155	19.9
W	82	Elderly	156	23.0
W	69	Elderly	166	36.2
W	43	Middle	154	18.5
W	55	Middle	162	34.2
W	43	Middle	171	20.5

(4) Fitting questionnaire. The subjects wear the product and answer a questionnaire about the fitting of the product. The questionnaire includes questions about the relevant dimensions of the products. The dimension is considered wrong when the subject prefers smaller or bigger.

(5) Multinomial logistic regression to predict the probability of a small, big or right fitting of the garment sizes. The independent variables are the tight, right and loose fitting of specific product dimensions. The logistic model predicts the probability of tight, right and loose fitting. The anthropometric measures that predict the fitting are selected with a stepwise process.

The hypothesis for our logistic model is that it is possible to estimate the fitting preference using the anthropometric measurement and the garment dimensions. This allows generating a linear model of the preference variables. Therefore, it is considered that the preference variables are the dependent ones and it is needed to search independent variables correlated and statistically significant with the dependent ones. In our case this independent variables are anthropometrical and garment dimensions.

The fitting preference is a categorical variable with three different possibilities. For this reason a multinomial logistic regression is used. This regression type is used when the dependent variable has more than two different categories for instance shorter, good and longer. In the multinomial-logit model one of the response categories (in our case good) is selected as a baseline, and then they are fitted logistic regressions models comparing each of the remaining categories (shorter/tighter and longer/wider) with that baseline.

Therefore, the multinomial logistic regression generates two equations. In our case the probability of failure 1 is the probability that the user assess the fitting as shorter/tighter (eq 1), the probability of failure 2 is the probability that the user assess the fitting as longer/looser and the probability of success is the probability that the user assess the fitting as good (eq 2).

$$\log_e\left(\frac{Probability.of.failure.1}{Probability.of.success}\right) = c_0 + c_1x_1 + \cdots + c_kx_k \qquad \text{(Eq. 1)}$$

$$\log_e\left(\frac{Probability.of.failure.2}{Probability.of.success}\right) = c_0 + c_1x_1 + \cdots + c_kx_k \qquad \text{(Eq. 2)}$$

The stepwise process for selecting the anthropometric variables has two main steps:

(1) Correlation test between variables. If two variables are much correlated (>97.5%), the variable selected is that experts (doctors or orthotists) consider more relevant and easier to measure.

(2) Eliminate the variables without statistical significance (ANOVA test, $p<0.05$).

Finally, the receiver operating characteristic (ROC curve) is used for choosing the probability of success (Brown and Davis 2006).

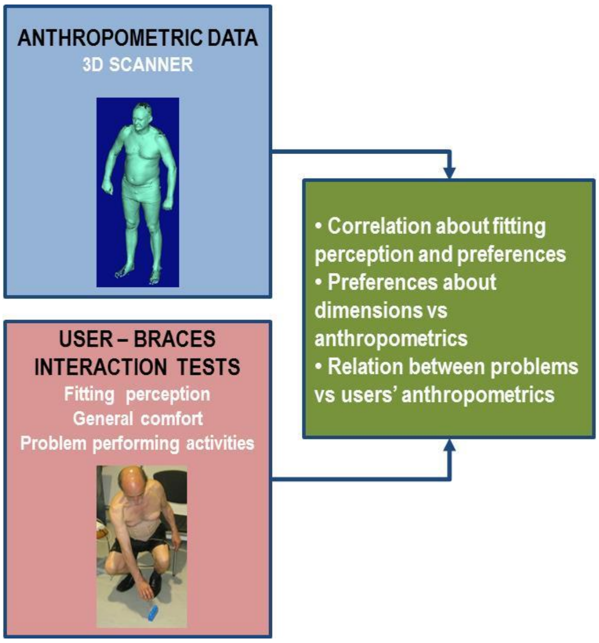


Figure 1. Example of fitting tests.

A similar procedure was applied to the clothes case.

2.2 *Definition of a new customised product development framework.*

During this phase, the end-user specifications are used in order to develop product customisation services to be used by end-users and professionals (configurators). These tools manage the consumer characteristics and preferences which are the key to individual customisation. A collaborative design environment made possible to define the morphological and functional characteristics of the end-user, to configure product style, and to individually personalise key product functionalities relevant to guarantee comfort and avoid health problems.

2.3 *Linking of the end-user needs with the new production technologies.*

This phase includes all the supportive developments to effectively link and integrate the new collaborative design framework (i.e. professionals and users) to the new production processes at manufacturing sites (from materials suppliers to final product assembly). The supportive developments are:

(1) Advanced CAM functions for the new production processes of stretching leather. Developed for customization of footwear.
(2) Development of innovative Life Cycle Analysis (LCA) instruments for addressed processes and products. Developed for any kind of customized product.
(3) Development of new production technologies for new customised functional materials and finishings. Developed for customization of footwear and apparel.
(4) Development of an automatic method for adaptation of product dimensions to atypical individual shapes and postures. Developed for apparel.

The supportive developments are described below, with the exception of number (4). This development is described in Kaiser et al. (2014) and Kaiser et al. (2015)

2.3.1 Advanced CAM functions for the new production processes of stretching leather

The stretching leather is an important material to improve the shoe comfort for people with diabetes. This material provides the aesthetical function of the normal leather, but with better elasticity properties. A stretch-leather can be customized through a continuous bounding, thermal treatment and chemical treatment. The leather is an organic material, it is a highly inhomogeneous and characterized by a main direction, according to which limited stretching takes place, beside typical aesthetic properties such as reflection, pattern, etc. Furthermore, depending on the animal hide, it is more or less thick, flexible etc.

For these reasons, advanced CAM functionalities are necessary to obtain more homogenous results to guarantee a controlled elasticity range (varying from 50 to 60%). The traditional meaning of CAM is associated to the programming of an operating machine, where the programming of tool path is the central task to be addressed and automated. Very specialized systems exist, in fact, which are able to calculate the optimal path of different tools, in order to effectively and efficiently realize artefacts based on a proper CAD model in which all the geometrical and functional information are designed and represented. The same is not true for different specialized process, where the notion of "tool path" is not that relevant, while the calculation of the optimal machine setup assumes a central role in the process design.

The application of CAM techniques in the context of an extended and cooperative enterprise moves instead the focus to the interaction between various actors in the supply chain, with the aim of integrating their expertise, from technical and managerial figures to final users, including machine operators and tool suppliers.

The traditional approach followed by typical CAM systems is based on a clear definition of the input materials and the desired results. Such an approach needs to be revised in favour of a less deterministic one, due to the high variability of results and the difficulty to foresee the actual behaviour of the materials (from various mechanical and physical points of view). A statistical approach is preferable, since it is based on experiences and documentation of the obtained results. In order to pass from product specifications to required machine configuration, necessary for the production, it is fundamental to identify the most important parameters, which are significant for the manufacturing process, and their related correlations. Once this information is available, it is then possible to link the values and typologies of parameters (or factors) to the quality of results considered as variable and somehow controllable.

For this reason, a cooperative, web-based CAM system has been developed, based on the rationales of Design of Experiments approach, in order to support the process of identifying qualitative and quantitative correlations between factors and responses, meant as qualitative results which are controllable by the manufacturing process (Montgomery 2001). The system allows the specification of parameters, divided in two categories: Machine Parameters and Process Parameters. In the first category, only the most significant parameters related to the machine configuration are taken into account: Air Break, Cylinder pressure, Carpet Pressure and Cylinder Temperature. In the second category, only the variable parameters of the joining process are here considered: Joining Path, Winding Pull and Velocity

This approach allows taking in account all possible combinations of the levels across such factors/parameters, consequently allowing the investigation and study of the related effects by each factor on the response variable, as well as the effects of interactions among the factors.

2.3.2 Development of innovative Life Cycle Analysis (LCA) instruments for addressed processes and products.

The application of LCA in the context of customized manufactured products poses a number of issues. From one side the possibility to introduce further sustainability features like reduction of unsold product in stock, efficiency in supply chain management and increased duration of traditional products (Brunø et al. 2013; Bernard et al. 2012; Zhang et al. 2011). On the other hand different barriers can seriously affect the implementation of sustainable policies when the efficiency is not properly monitored (Brunø et al. 2013; Zhang et al. 2011). Redundancies in the factory waste and the shift of the stock surplus problem from product selling to product manufacturing can in fact nullify the foreground benefits. Then as primary issue a proper characterization of real effects seems necessary (Brondi et al. 2014). LCA can represent a proper methodology to assess product sustainability cause to the intrinsic tendency to spot mass and energy balances along the whole product life cycle (Brondi et al. 2014; Hugo and Pistikopoulos 2005). Furthermore, being based on the ISO standard, such methodology can produce reliable certification framework. The proper adoption of traditional LCA to the manufacturing context and particularly within a customized environment can produce general and specific issues as reported hereafter.

- General issues are related to the company processes adaptation to the life-cycle inventory and assessment. In particular it can be complex to adapt the business perspective especially within the small and medium enterprises, together with the view of the entire life cycle (Hagelaar and van der Vorst 2001). When assessments are performed internally the limited view on life cycle produce the use of literature and general purpose database, the main effect is then the limitation of the result reliability. In addition a misalignment can be still registered between company environmental assessments and product design; this misalignment affects both the temporal progression regarding changes on the final product and the type of required data to provide these changes (Bojarski et al. 2009) . In fact the design of a product can imply a limited set of parameters which can be reusable for environmental impact assessments.

- Specific issues are related to the LC data reusability within complex reconfigurable supply chains. Once a LCA study is performed it can be hardly reused for other purposes (Brondi et al. 2014; Nwe et al. 2010). Furthermore product comparison implies a different set of LCA rules, while changes in the functional unit or in the single processes can nullify the study’s reliability. In addition, when benchmark data are available the quantitative results are commonly referred to entire life cycles. A different focus on product composition or on a single life-cycle phase can be then inhibited. Finally the limited use of quantitative framework in the eco-labelling context for shoes and textiles implies a limited awareness both of end user and stakeholders.

To sum up both these barriers types contribute to limit the rapid generation of data. The support to a concurrent design and assessment of sustainable customized tools seem then require a different procedure to properly adopt LCA in the fashion area.

In the Fashionable project a tool for the rapid and reliable assessment of the environmental impact of new materials has been developed. In particular a modular approach has been followed in order both to rapidly introduce new environmental assessment in design tools and to merge product-design, PDM and eco-labelling processes for footwear and fashion products.

2.3.3 Development of new production technologies for new customised functional materials and finishings.

State-of-the-art textile finishing production concepts, either chemical or physical, are typically based on homogeneous wet treatments of textile fabrics from roll to roll (and post-treatment like drying, consuming a lot of energy), the so called foularding (Heidemann and Schollmeyer 1985; Hund and Hund 2011). Specific textile functions like liquid repellence, antistatic behaviour or antimicrobial activity are typically given to a textile along its complete length (e. g. 500 m) and width (e. g. 1.60 m). These processes lack flexibility and are not suited for small lot size customized functionalization of textiles, which is necessary for individualised clothing, footwear and orthotics for target groups.

Four approaches are tested to decide the best for small lot size customized functionalization:

- Airless spraying by rotor plates (ROT): This spraying method with rotating plates is a technique near to an industrial finishing process. It is the best method to apply one agent on the whole width of a roll to roll process (Schindler and Hauser 2004).
- Air driven jet-spraying (JET): This process variant is characterized by an air driven two phase spraying with an open mechanic valve and the dosage by an external pump system printing with a micro dosing system (Schindler and Hauser 2004).
- Three-dimensional spray finishing (3DSF). A multi axial robot adapted with air-driven spraying in a two-phase spray jet

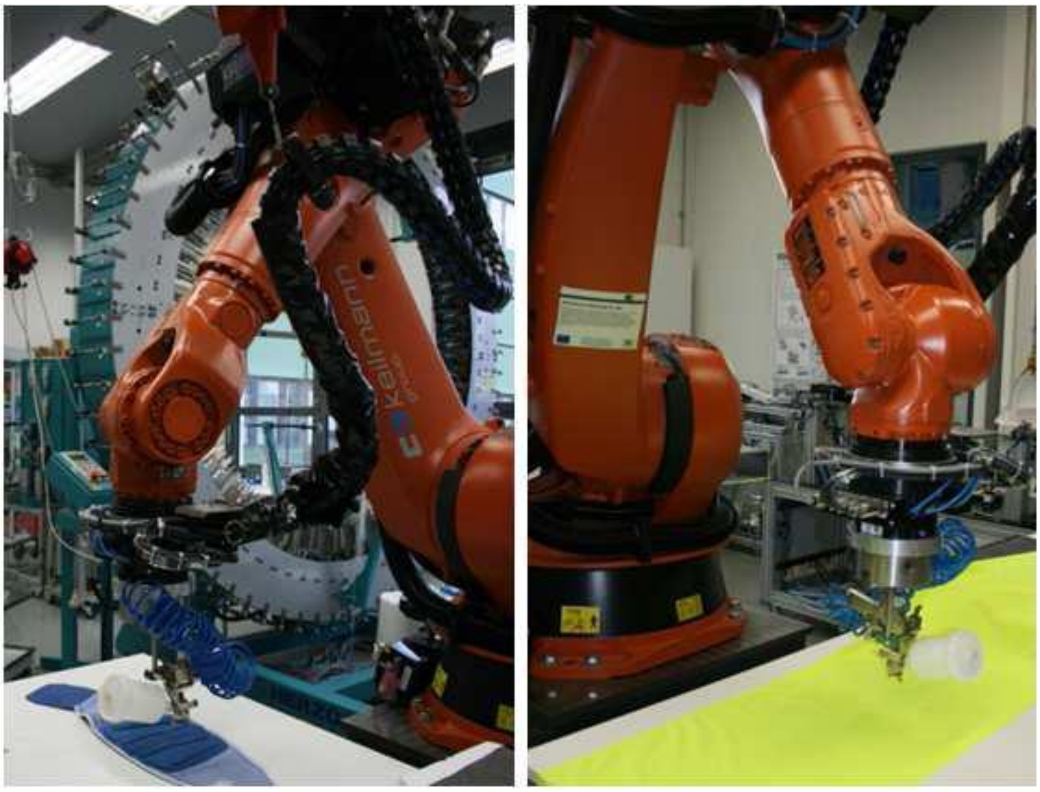


Figure 2: Finishing approach with a multi axial robot

- Digital functionalization (DF). Digital applying of finishing agents with a modified printing system. It is a one phase jet spraying with valves in the nozzle. The agent is set under pressure and if the valve opened the nozzle the jet begins to spray.

Figure 3: Digital Functionalization. Experiment printing a checked pattern with finishing agent

3 Results and Discussion

3.1 Needs and requirements of the targeted population

The next tables are a summary of the main requirements for the 3 products.

Table 2: End-user requirements for footwear

Plantar pressure	Avoid excess pressure point (lack of sensitivity in the plant)
Dorsal pressure	Avoid high pressures over the foot dorsum. The inner surface must be soft and smooth.
Fitting	Footwear fitting has to be right since the beginning, without period of adaptation. The toe room must assure they are not press and allow its movement.
Perspiration	Avoid moisture (infections, blisters and ulcerations).
Thermal isolation	Protect feet against hot and cold environments (lack of thermal feeling)
Flexibility	Minimum effort to flex footwear (arthritis, degenerative osteoarthritis)
Foot-shoe friction	Avoid foot-shoe friction. Foot displacement inside the footwear (rubbing or ulcerations)
Shoe-ground friction	Improve shoe-floor friction (slipping during the heel contact and the take-off)
Shock absorption	Cushioning to prevent the joint degeneration (*arthropathy*)
Ground insulation	Footwear must isolate the foot from the irregularities of the ground (propioception).
Weight	Light footwear to facilitate gait (elderly people).
Stability	Provide foot support to avoid balance problems.
Easy the put and take off	Mainly to elderly people or mobility problems in the hands.
Aesthetics	Footwear must be fashionable and trendy footwear.

Table 3: End-user requirements for clothing

Fitting	Wheelchair users need loose fitting in neck, chest, abdomen, bottom and legs. They also need longer lengths at legs and at the back of shirts, sweaters, jackets and coats.
Usability	Users need specific openings to facilitate the put on / off process. Closures (Easiness to put on and off) Paraplegics prefer zips, Velcro and elastic bands. Quadriplegics prefer Velcro o elastic bands.
Freedom of movement	Wheelchair users have limitation in their movements: garments must not increase these limitations. The areas where users feel more movement restriction due to garments are back, shoulders and arms.
Perspiration	The presence of moisture in the garment or between garment and the chair may contribute to the appearance of infections. Moreover, moisture may increase friction and produce blisters and ulcerations. The areas where users sweat the most are bottom, chest, dorsal, lumbar, neck and abdomen.
Thermal isolation	The lack of thermal feeling of paraplegics and quadriplegics has to be considered when designing garment. The garment must protect the body against hot and cold environments. Main areas suffering thermal discomfort are lower limbs and hands.
Friction	Friction between clothes and the chair must be avoided to prevent the appearance of injuries or rubbing. It is also important to increase durability of garments in the areas with more friction

Aesthetics	Comfortable and suitable garment is not opposite to fashionable and trendy garment. Users claim for more aesthetical garments.

Table 4: End-user requirements for orthotic back braces

Correct fitting	Orthosis adapted to the different body shapes depending on the users' anthropometrics. Women are more affected of these fitting problems due to the fact that the orthotics are not adapted to their hip's shape.
Perspiration	Avoid moisture between the user and the orthosis (discomfort, chafing).
Control	Control undesirable motions and permit motion where normal function can occur.
Flexibility	Design flexible areas to avoid discomfort without losing necessary rigidity.
Fastening	Adjustable fastening system to avoid oppression feeling. Elderly and people with osteoarthritis are the users that have more problems in order to adjust and fasten the back braces. They do not have enough strength or mobility
Usability	Orthosis adaptable to different situations: Working, sports, wearing tight clothes... Orthotics easier to wash with the washing machine. Easy the put and take off controlling the force of the closure system, (elderly, osteoarthritis).
Aesthetics	Make the orthosis undetectable under the clothes to improve users' social acceptance. Use attractive colours and avoid the use of the flesh colour.

In what follows, it is shown the multinomial logistic model that relates the front length of the back braces with anthropometric measures.

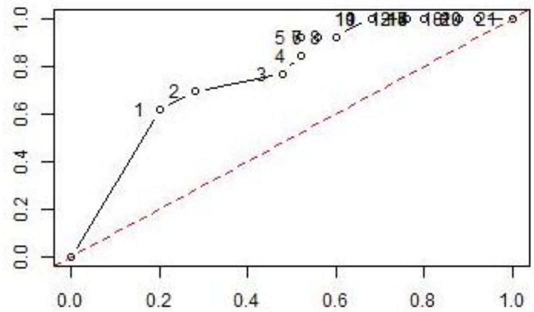
$$\ln \frac{Probability.of.failure.1}{Probability.of.success} = 15.89 - 0.32 * \text{Th11.width} - 1.82 \frac{Distance.C7.ASIS}{Fron.length}$$ (Eq. 3)

Where:

- Distance.C7.EIAS is the vertical distance between the C7 vertebra and anterior superior iliac spine (ASIS)
- Th11.width is the width of the trunk at the height of the TH11 vertebra.

Then, the front length value is calculated with the next equation. Where $\frac{Probability.of.failure.1}{Probability.of.success}$ is the threshold.

$$Front.Lenght == \frac{-1.82*Distance.C7.ASIS}{-15.89+032*Th11.width+\ln(\frac{Probability.of.failure.1}{Probability.of.success})} \quad \text{(Eq. 4)}$$



The ROC curve (see Figure 4) is created by plotting the fraction of true positives out of the positives (TPR = true positive ratio) against the fraction of false positives out of the negatives (FPR = false positive ratio), at various threshold settings. TPR is also known as sensitivity, and FPR is one minus the specificity or true negative rate.

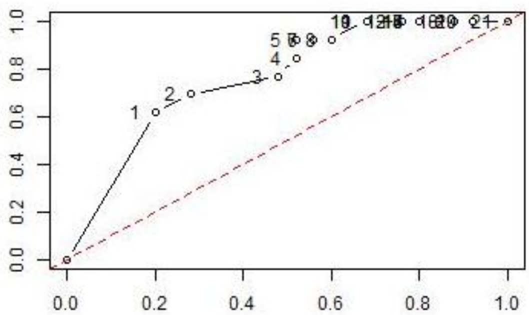


Figure 4: ROC curve

Similar models where obtained for all the relevant dimensions that the manufacturers need to design the patterns. Therefore, the methodology proposed is able to provide the needed rules for pattern design.

3.2 New customised product development framework

The new customized product framework consists of product configurators for the customers and knowledge repositories for the manufacturers.

The configurators help the customer in order to select the best options considering the capacities of the customer (

Figure 5).

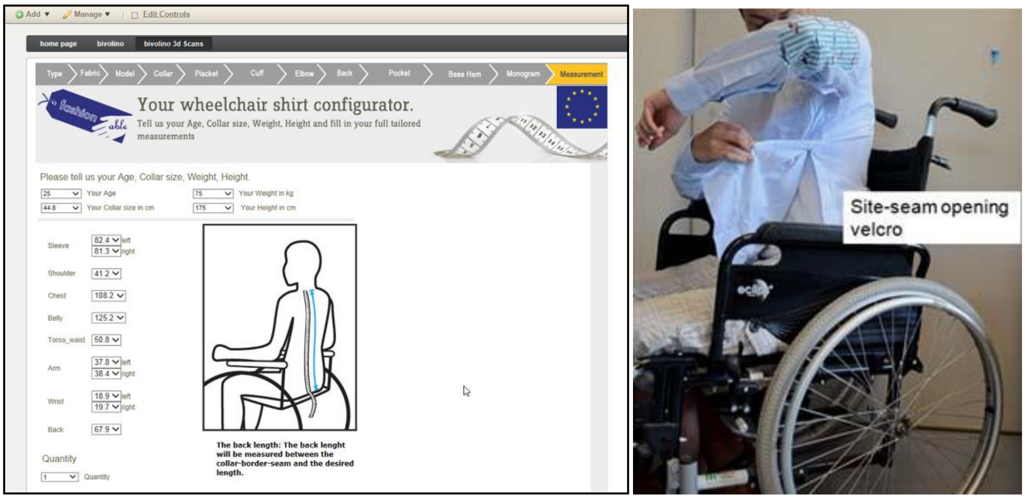


Figure 5: Clothing configurator for wheelchair users (© Bivolino)

The configurators also include visualisation and an annotation tool for 3D scan. This tool is useful for the manufacturers and the customers. The list of annotations is stored along the customized order, for subsequent retrieval (

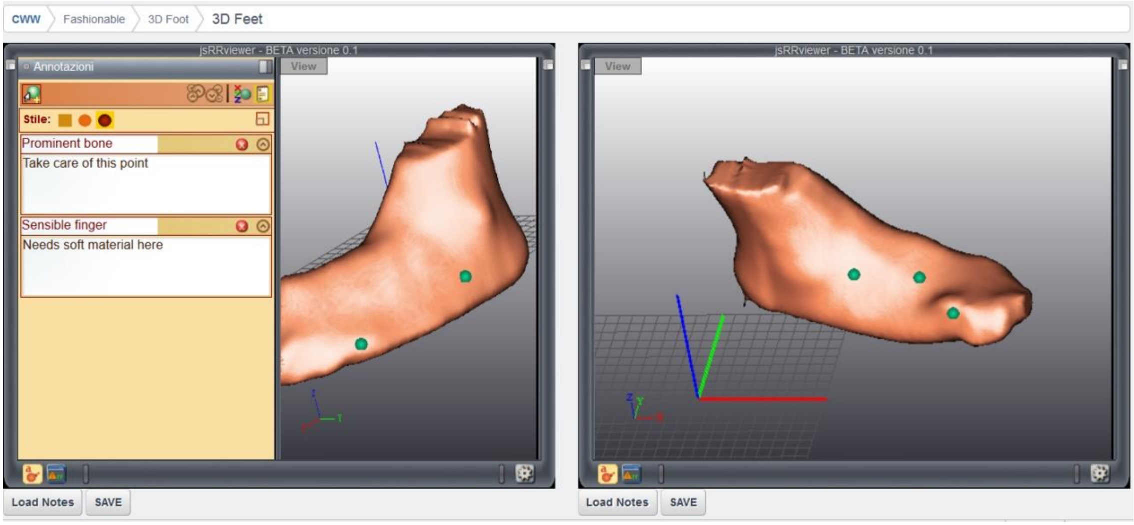


Figure 6).

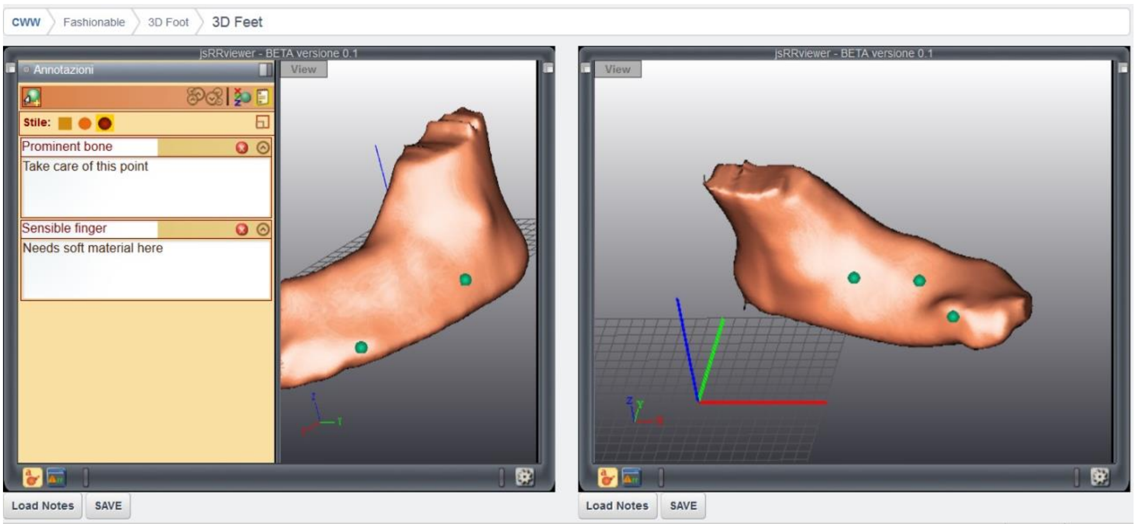


Figure 6: Footwear configurator. Screenshot of the 3D visualisation, navigation and commenting tool (© SYNESIS).

The configurators are linked with knowledge repositories that relate the healthy problems of the end-user with the materials. For example, the material has a score according to Eq.5.

$$Score(MAT_k)=\sum_i \sum_j P_i\,(MAT_k)\times R\left(P_i,NH_j\right)\times I\left(NH_j\right) \qquad \text{(Eq. 5)}$$

Where:

- $P_i(MAT_k)$ is the property of the material (e.g. rigidity)

- NHj is the health problem of the end-user (e.g. skin ulcer).
- I(NHj) is a level assigned to the health problem. (e.g. the end-user assigns the value 0 to 5)
- $R(P_i,NH_j)$ indicates the level of relation between Need and Property. Relation can be positive or negative.

This way the knowledge repository recommends a specific material according the end-user needs.

3.3 Advanced CAM functions for the new production processes of stretching leather

The result of the design of experiments (see section 2.3.1) was that the main important properties which can affect the final perceivable quality of stretch leather are: thickness of the final product, stretch anisotropy, elasticity, wrinkles and delamination. But, the design of a new textile product, especially when both aesthetical values and functional qualities must be considered, involves the expertise of several experts (workers with experience), each contributing to the project with a specific piece of information and ideas.

This is the case for the development of a new stretching textile, whose final mechanical properties are among the main added values, along with aesthetical and tactile feeling. Such a development process spans between stylistic, design and industrialization aspects, which must all be controlled and checked from the very beginning, following an incremental and improving approach.

The central technology adopted by the FASHION-ABLE project for stretching leather is represented by the calendering process, applied to the component materials that compose the final product. Such a process is based on a deep analysis of the required machine behaviour that, in turn, depends on the proper choice of reciprocally interacting parameters and the methods applied for the material feeding. The various experts are often involved in a non-strictly sequential order, and therefore technical changes overlap with the introduction of new ideas. Moreover, the experts have to participate in the process suffering an irregular planning, often limited by geographical distances or even the impossibility to meet physically.

The involvement of the customers, often requested in case of customized development, and the technical support by machines and tools builders extends even more the needs for an effective cooperation. Given such a scenario, the FASHION-ABLE CAM system has been developed taking as central requirements the ability to manage an agile cooperation between partners and an incremental development process. The system is therefore based on blend of harmonically integrated modules, including a web application to support remote communication between technical actors and a SCADA/Machine control system that provides a clear guide line to the relevant machine parameters which are relevant for the fulfilment of the best product quality.

The final set of parameters control the main mechanical and thermic elements of the process, along with the devices, which verify their behaviour during machine operations by means of appropriate sensors.

Based on the need to collect and to exploit expertise on the process setup, the information have been organized in order to associate the past production quality checks to each of the developed textile products. This approach enables the product developers to elaborate past results and take decision based on their verified quality.

The machine configurations are therefore organized in so-called “recipes”, each one characterized by specific parameter values, material paths around the calendering cylinders and reporting of the verified results. Several tested recipes are available to be reused in any new production, with a reference to the optimal one for the specific product variant.

Each recipe, besides documenting all the relevant process details and machine configuration parameters, is associated to the production order that originated the machine run. Thus maintaining a reference to the actual result and the corresponding material quality checks, including customer satisfaction.

In addition to the cooperative and shared programming of the machine optimal configuration, the system offers the possibility to select the desired material paths by mean of an interaction over a web-based 3D environment.

This functionality is integrated in the overall architecture of the system, offering a coherent user interface that helps to uniform, hence to harmonize, the user experience of operators in various departments of the company (e.g. design, process planning, plant). Other partners along the supply chain, which are usually residing in geographically distant locations, are also allowed to access to this functionality, which greatly helps the user interaction especially in presence of linguistic barriers.

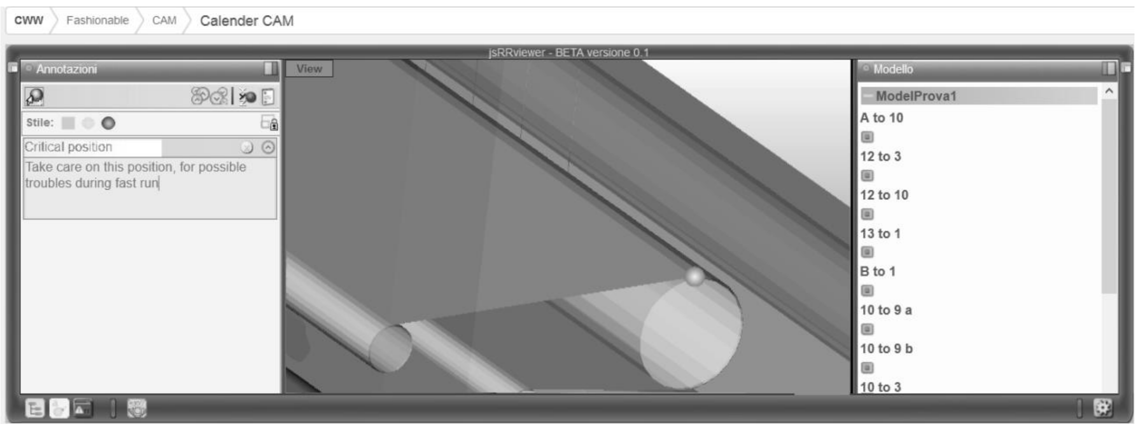


Figure 7: Web based 3D cooperative configurator for calendering machine

The web 3D cooperative CAM application supports the involved operators in the interactive definition of the optimal materials paths and the machine configuration parameters. In addition, it supports the online real time modification of the CAM model, the exchange of immediate comments, possibly stored for future documentation.

The new CAM system has contributed to develop a new family of stretch-leathers based on textile materials and fabrics bounded with leather, improving the mechanical stretch and enlarging of the working area. Such a result was possible thanks to the control of machine parameters, enabling the customization of mechanical properties (elasticity, resiliency, surface resistance, thickness) and functional properties (adsorption, breathability, softness, thermal regulation). In addition, customization of material aspects was possible, including orientation of the stretch effect in specific directions (mono, bi-stretch), thickness which can be processed and colour customization.

3.4 LCA tool to ensure environmentally sustainable development and production

The new tool has been designed to support the constant reuse of environmental studies. Particularly for the supply of new technical materials (i.e. nano-materials) and sector-specific components (i.e. footbed) in order to counterbalance the high variability of the fashion product chain. Environmental Product Declaration (EPD) general rules already provide a partial harmonization between the Product Category Rules (PCRs) of the upstream materials (e.g. textiles) and the PCRs which are defined to downstream products containing such materials (e.g. footwear).

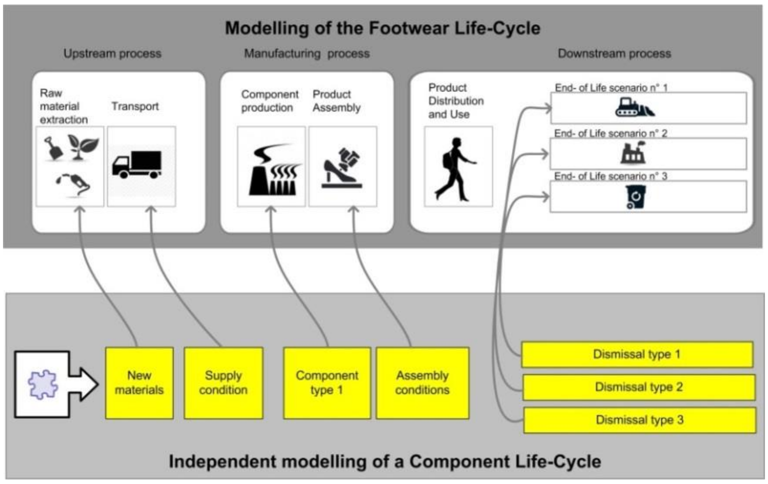


Figure 8: Integration of LCA studies for new components within existing LCAs studies for footwear

The modular structure of the life cycle aims to encourage the creation of a specific sectorial database at international level to integrate data in existing LCAs (

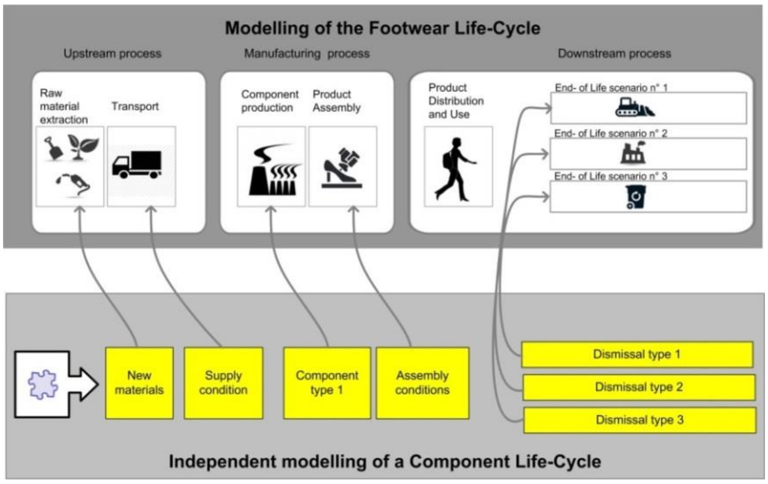


Figure 8). Such modular structure can produce the transformation of the entire life-cycle assessment in terms of combination of different gate-to-gate assessments which are referred to single components rather than to the entire product. The same standardized partial studies are thought to be manageable even by non-expert analysts while keeping at the same time an adequate level of precision.

In particular the development of independent information modules could facilitate the implementation of the different LCA studies for a wide variety of footwear models rather than limiting the EPD registration to few cases. Methodology description is summarized in equation 6, 7 and 8 and described in Table 5.

$$\boldsymbol{E}_{\mathrm{f}} = \sum_{\mathrm{i}=1}^{\mathrm{N}} \boldsymbol{p}_{\mathrm{i}} \boldsymbol{M}_{\mathrm{f}} \quad \text{(Eq. 6)}$$

$$\boldsymbol{p}_{\mathrm{i}} = \sum_{\mathrm{j}=1}^{\mathrm{L}} \boldsymbol{p}_{\mathrm{ij}} \quad \text{(Eq. 7)}$$

$$\boldsymbol{M}_{\mathrm{f}} = \sum_{\mathrm{i}=1}^{\mathrm{N}} \mathrm{m}_{\mathrm{i}} \quad \text{(Eq. 8)}$$

Table 5: Variables in equations (6), (7) and (8)

E_f	Environmental profile of a customized fashion product
M_f	Weight of a product model
m_i	Weight of a single component
p_i	Unitary Environmental profile for unit mass referred to a single component life cycle
N	Total Number of product components in the bill of material
L	Total number of standardized life cycle phases for a single component
p_{ij}	Incremental environmental impact for single life cycle phase

In order to make reusable the individual assessment, specific actions have been adopted:

- Use of a consistent terminology and LCA data inventory has been produced with reference to the EPD framework (PCR 2933 - Leather based footwear ; 2952 safety footwear ; 27922 - Nonwovens for clothing, protective clothing and upholstery, Nonwovens for other purposes than clothing; 27190 - Floor-cloths, dish-cloths, dusters and similar cleaning cloths).

- Result comparability with reference to the same physical units independently from the functional unit definition (accounting LCA).
- Modularization with reference to realistic life cycle phases for the reference product.
- Use of terminology and methods consistent with the technical standards in the textile and footwear area.

As far as the final tool algorithm a basic description is provided hereafter (see

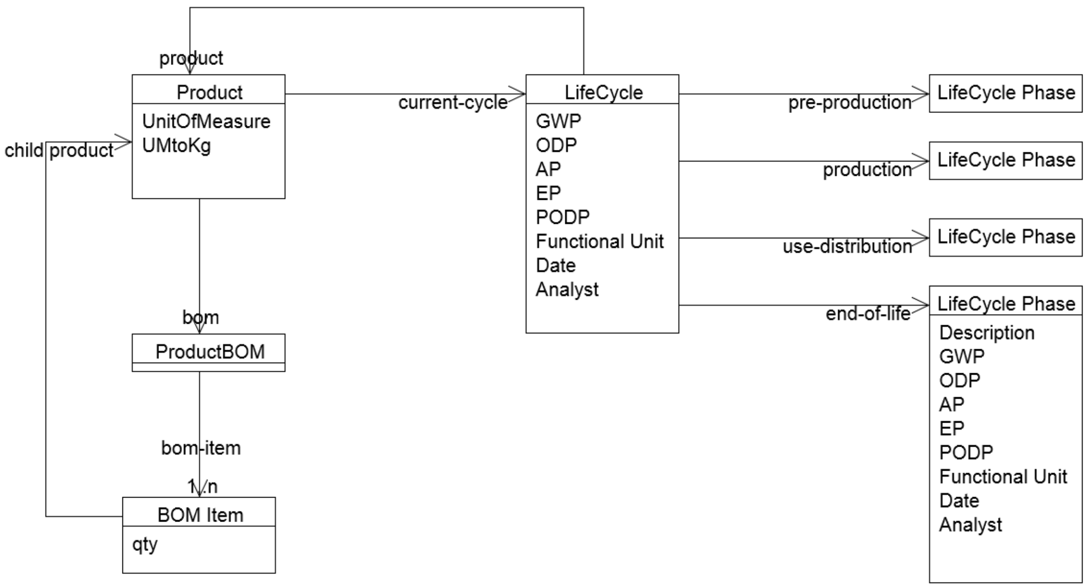


Figure 9).

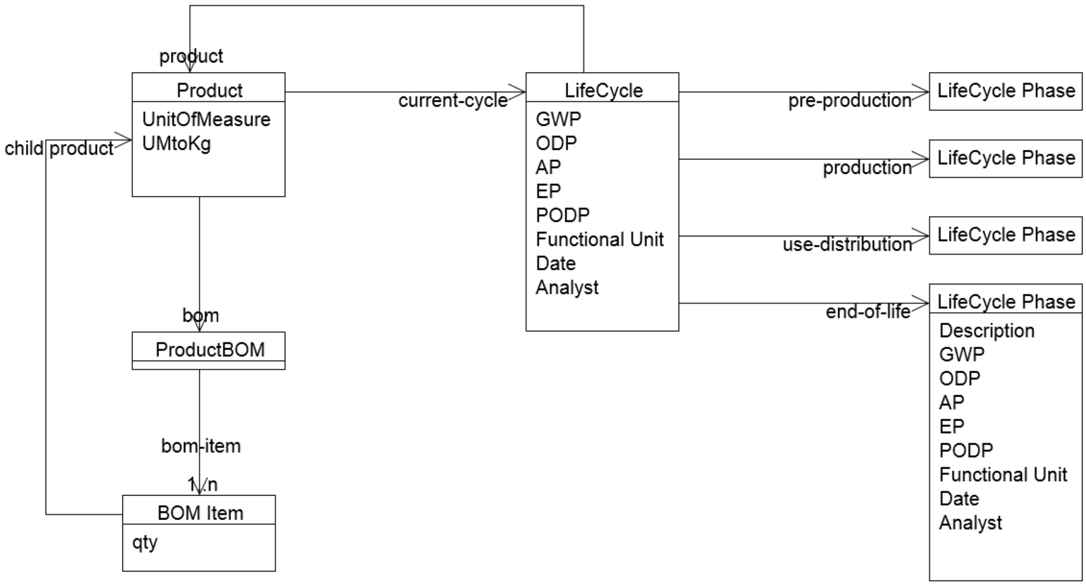


Figure 9: LCA algorithm a basic description

The methodology to modularize data is integrated into a computational tool based on the following features: The final product is analysed as a set of different component life cycles, then multiple partial information are created for the same type of material. Once the material is associated to a component, its life cycle is assembled through the selections of life cycle standard phases. Once all the life cycle phases have been selected, the environmental profile of the final product is calculated. Finally a database for a list of materials used within the project FASHION-ABLE is produced.

More in detail, the following steps can be identified by the user perspective.

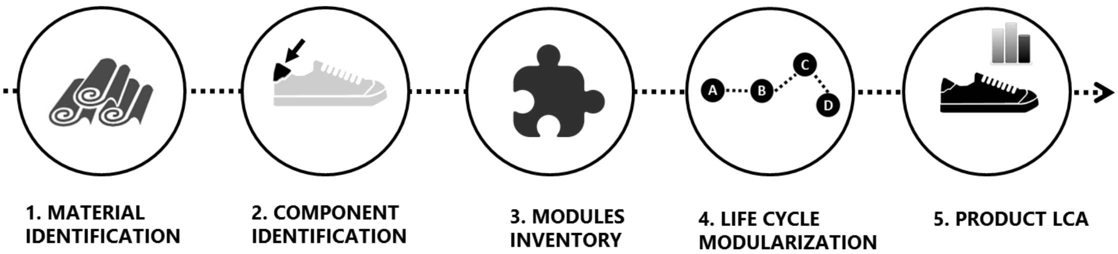


Figure 10: LCA steps

(1) Material identification:	A specific material is selected to be added to the Fashionable database or to a specific new product

(2) Component identification:	The specific use of the material within the product is specified. An inventory for a new component integrating the new material is created
(3) Modules Inventory:	Independent information modules are added with reference to specific component life cycle phases
(4) Life cycle identification:	Impact on different life cycle phases are calculated
(5) Product LCA:	On the basis of a proper aggregation from congruent life component life cycle a standardized Product LCA is structured.

The preliminary results on product LCA seem comparable with traditional static LCA for the same product category.

A particular feature has been added in order to introduce a categorization of the final environmental performance. Common environmental profiles are in fact expressed as ODP - Ozone Depletion Potential (in kilograms of CFC equivalent), GWP - Global warming potential (in kilograms of CO2 equivalent), POCP - Photochemical Oxidant Creation Potent (in kg ethene-equivalent), EP - Eutrophication Potential in kg PO4-equivalent, and AP - Acidification Potential in kg of SO2 equivalent. In order to introduce a benchmark value each environmental profile is clustered in performance classes according to negative or positive closeness to an average environmental profile within the same component category. In the fashionable tool the performance class is reported close to the environmental parameter for each resulting value.

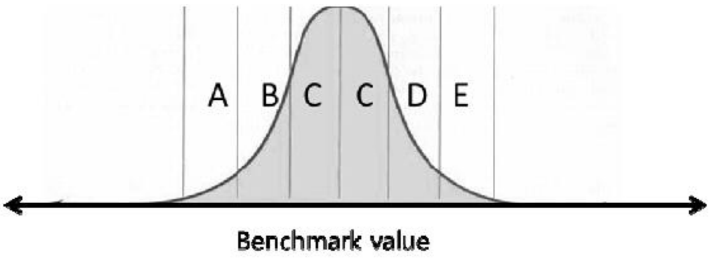


Figure 11. Classes

The classes A and B refer to a positive shift compared with the benchmark, classes D and E, instead, refer to a negative value.

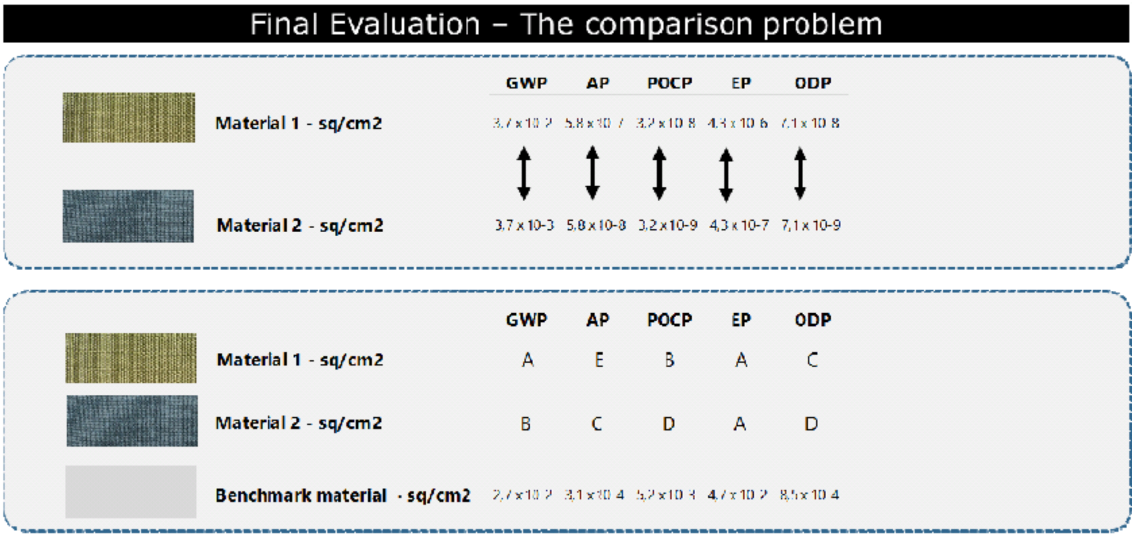


Figure 12: Screenshot of the LCA tool

Therefore, when a comparison between the two materials occurs the profile of a third type of “benchmark” material is used in order to reproduce the average impact of all possible materials present in the database. In this way the relative comparison of two different materials is less important than the whole environmental performance. This type of evaluation allows eco-designers to understand the environmental performance of the material in an immediate way without further extrapolations.

3.5 New flexible finishing processes

The evaluated finishing technologies differ in many aspects. Although padding is the standard industrial textile finishing process, its resource efficiency is rather low due to high consumption of finishing agent and energy for drying. Rotational (ROT) and pressure supported spray techniques (JET, 3DSF) have lower energy consumption due to less water application, but rather high material consumption because of overspray effects. These techniques are therefore rather uncommon in textile functionalisation processes. Digital fine spraying (DFS) has high resource efficiency because of almost no overspray and little water application.

Set-up times are in principle comparable between the techniques. However up to 8 functions can be applied to a textile in one step by DFS and only 1 – 3 with the other techniques. Set-up and process times, therefore, can be substantially shorter by DFS realizing multi functionality in one step instead of two or more steps by standard padding or spray processes.

Repetition capability and process robustness is high for the standard industrial padding process. However it has no capability for localized functionalization and the minimum textile web length for an economic efficient process is around 50 m of fabric. The process robustness of other evaluated finishing techniques is lower due to higher levels of machine complexity and specific requirements of fluid properties for the finishing agents. Industrially sufficient repetition capabilities can be achieved, nonetheless.

The digitalized fine spraying using digital controlled magnetic valves with a very short distance to the material surface is particularly useful and outstanding for localized application of multiple functions at high resolution and economic small lot manufacturing. Lateral resolutions below 1 mm are possible with DFS. Maximum lateral resolution ranges of other spray techniques are at 10 cm due to overspray.

The time to market is short for techniques already established in textile industry like rotational spraying and digital functionalization for color printing. Some specific process parameter adaptations or process developments are still necessary for wide industrial use in textile functionalization.

The initially targeted approach for flexible localized functionalization using air spraying (2D and 3D) is technically feasible, but not efficient. The digital functionalization by fine spraying using digital controlled magnetic valves with a very short distance to the material surface, using chemicals without auxiliary air (by diffusion), allowing a more precise functionalization, is easier to apply, needs less resources, and – due to development for digital printing, e.g. on carpets- has a shorter time to market. In particular a precise local, multi-functionalization is possible with the fine spraying technology, because no overspray occurs.

Additionally set-up times are shorter, and scalability/flexibility is higher, using multiple magnetic valve units. The used chemistry is treated more save and smoothly. And finally, the fine spraying allows additional features like e.g. making markers or completely other functionalities.

The

Table 6 shows a quantitative comparison of the different techniques.

Table 6: Quantitative analysis of textile finishing techniques

	Padding	ROT	JET	3DSF	DFS
Textile industry readiness	Standard (finishing)	Established (finishing)	Uncommon	Uncommon	Established (color printing)
Energy Efficiency	Low	Medium	Low-Medium	Low-Medium	Medium-High
Material Efficiency	Medium	Medium	Low-Medium	Low-Medium	Medium-High
Approximate set-up times	30 min	30 min	30 min	30 min	30 min
Repetition capabilities/ process robustness	High	Medium	Medium	Medium	Medium-high
Precision capabilities for localized functionalization	Zero	Very low	Medium	Medium	High
(lateral resolution)		> 0,5 m	> 10 cm	> 10 cm	> 0,5 mm
Flexibility	Very low	Low	Medium	Medium	High
functions per treatment	1 - 2	1 - 2	1 – 3	1 – 3	up to 8
Minimum fabric length/ lot size	50 m	50 m	50 m	single item	5 m
Time to market	Zero	Short	Medium	Long	Short-Medium

4 Conclusion

FASHION-ABLE provides to the European innovative and customization-concerned SMEs the technological means that will enable the agile and eco-efficient production of personalised products addressing the complex individualised needs of growing market niches out of the scope of mass-produced goods in terms of health and performance.

In particular, it has been demonstrated, that the methodology applied is feasible for developing the new cross-sectorial technologies for three highly challenging target groups: fashionable footwear for diabetic feet, fashionable clothing for wheelchair users, and high-performing textile compression bandages for obese people. However, further research is necessary to extend the methodology developed to other type of products and people with other necessities or disabilities.

The harmonized combination of developed technologies will have a direct impact on health, comfort, safety and quality of life of the targeted populations: diabetics developing diabetic feet; physically disabled people requiring a wheelchair; and sufferers from acute periods of musculoskeletal disorders which prevalence increases with age and weight. Furthermore, the cross-sectorial approach will allow for extending and up-scaling functional customisation with little effort to future unexpected functionalities as well as to be transferred to other products and high demanding markets.

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