

# Integrating modern virtual engineering tools in footwear design and development

**P Azariadis, P Papagiannis and Z Koutkalaki**

University of the Aegean, School of Engineering, Department of Product & System Design Engineering, Ermoupolis, Syros, GR84100, Greece

azar@aegean.gr

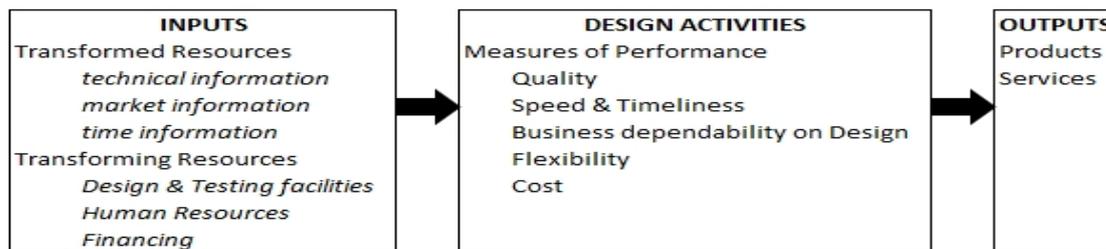
**Abstract.** Footwear prototyping is constrained by significant volume of “sampling”, time to market pressures, cost implications and the failure of the industry to attract and develop high quality professionals mastering modern computer-aided product development. Computer-Aided Engineering (CAE) and material selection are becoming increasingly important transforming factors of this process raising the question of how to best integrate them into the design function considering not only infrastructure issues but also human resources and financing. Their role in footwear development is presented in this paper, based on the view of design as a multistage process subject to Concurrent Engineering. Proposed interventions to the design process for exploiting modern CAE and material selection tools are discussed, taking into account the business Value Chain Model and modern Cloud Service approaches. Innovative approaches to harness the processing power of modern CAE tools are identified and related to business practices, considering, also, the role of product development professionals and financing constraints. In particular, the application of the cloud service model of managing Software as a Service is discussed along with relevant opportunities and limitations. The paper concludes with an overall assessment of the impact that this model may have on the footwear industry.

## 1. Modern Footwear Development

Footwear range from established traditional look-like products (e.g. classic leather shoes) to highly innovative complex structures utilizing modern materials and the state of the art in textile and additive technologies (e.g. wrap knitting, nanotechnology, 3D printing). They are assemblies of multi-material parts with extended supply chains, so formulating an effective product strategy dictates analysis of a complex global political, economic, social, technological, legal and environmental operating macro-environment [1], [2], [3]. Aligning with fashion and consumers' behavior are not the only challenges to address. Products have to comply with standardization requirements. They also need to achieve acceptable performance, comfort, durability and reliability for the intended use. Additionally, they have to comply with consumer safety, environmental and sustainability requirements. Operating globally is complicated due to a volatile political and economic environment that affects both demand and supply, driving material substitution and assembly location decisions. This is further affected by new trade wars and escalation of tariffs and other barriers to trade. In global trade, managing human resources and stakeholders means dealing with varied educational levels, different cultural and linguistic backgrounds and different approaches to problem solving and work organization. The members of footwear design teams may well be based at distant locations around the world.



Today, the effective and efficient development of new products has become a competitive advantage [3]. Although the contribution of Strategy, Financing, Human Resource Management, Purchasing, Logistics and Marketing cannot be ignored, Design is the heart of product development. Design is a process with inputs, outputs and performance metrics [1], [4] as depicted on Figure 1. There are five stages in the process: conceptualization, concept screening, preliminary design, evaluation and improvement, prototyping and final design [4]. These overlap, giving rise to the concept of concurrent engineering and its variants, which are enhanced through the use of Information and Communication Technology (ICT) tools, and Product Data Management (PDM) [5].



**Figure 1.** The Design Process (Adjusted from [4]).

In the footwear sector, prototyping usually requires a significant volume of “samples” prior to finalizing the details of the final product [5]. In addition, time to market is short, whereas overall product cost pressures are often significant. Furthermore, cost implications push product development budgets down, constraining design. Another issue is that the industry, generally, has failed to attract high quality professionals to staff critical development positions. Footwear designers have manufacturing or design-artistic background; however, most of their skill base development takes place through long practical industrial apprenticeships with limited exposure to modern scientific and engineering advances, in most cases.

Several frameworks to improve processes in the product assembly industries have been proposed ranging from incremental change ones (e.g. Total Quality Management) to radical Business Process Reengineering. These frameworks rely heavily on integrated ICT tools [6]. Modern Enterprise Resource Planning (ERP) systems incorporate PDM capabilities to support product development functions. Besides managing the extended supply chain, they even offer product style management capabilities, though they cannot address product visualization, pattern engineering, tooling development, as well as, product performance and sustainability assessment. With regard to product geometric modeling and rendering, pattern engineering and tooling (lasts, molds, cutting dies) there are already commercial CAD/CAM solutions, with increasingly improved interoperability. This, though still hindered by many complications [7], tends to increasingly satisfy the needs of several companies around the world. However, the industry has not managed to integrate CAE into their processes yet. In addition, during the last 20 years, the footwear sector has seen the emergence of several supplementary innovative aids to product design. It is the purpose of this paper, to revisit modern footwear design in the light of these advances and identify alternative practices that will facilitate increased effectiveness and efficiency of the process.

Technology has the potential to transform any process, but the ultimate success depends on the people involved. Access to knowledge and enhanced decision-making, both supported through improved training are of utmost importance [6]. This paper takes into account this view and also considers the third transforming resource input to the design process: financing. Human resource development and technology come at a cost that most enterprises cannot easily absorb into their budgeting. Fortunately, innovative cost-effective approaches to harness the processing power of modern CAE tools do exist and will be discussed along with their relation to business practices.

## 2. Computer-assisted material selection in the footwear industry

Material selection software addresses performance, consumer safety, environmental and sustainability aspects of design. With regard to performance, general engineering material-selection software cover common industrial materials used in footwear (e.g. wood, alloys, plastics, coatings, adhesives). Some interesting approaches to dealing with the far more challenging textiles, leather and footwear composites, including “shape memory” foams and membranes, also exist. Textile fabrics, in particular, are complex products and their final properties depend on fiber and yarn characteristics, fabric geometry, as well as any associated dyeing and finishing process. Within different design solutions for clothing, some applications and databases are also of interest to footwear. The LibTex database [8] based on analytical and regression models can be used to calculate fabric performance characteristics from fiber, yarn and textile design parameters. Though information on tensile characteristics of simple fabrics is useful, several textiles used in footwear manufacturing have been altered through special finishing processes, stiffened or used in composites. Also, several other critical problems related to the cyclic loading of 3D footwear structures are not easy to address. A database of textile, leather and footwear materials was also developed as part of the Envirotex Design project [9], in order to support the Interactive Matrix, a product performance evaluation module based on neural networks.

Regarding consumer safety and sustainability, both product and process aspects have to be considered along the supply chain. Relevant assessment methodologies can be facilitated through ICT aids. Most general-purpose material-selection applications offer environmental assessment capabilities that address substance restriction issues, carbon footprint, embodied energy, water usage, resource consumption, end of life and supply risk aspects. There are few applications specifically developed for the footwear industry. These have varied degree of coverage for materials and processes. Some well-known aids are the Higg Index Tools by the American Sustainability Apparel Coalition [10], the ShoeLaw tool [11] on legal requirements for footwear products and processes, the ShoeBAT tool [12] on Best Available Techniques for footwear production, the CO2SHOE estimator [13] for carbon footprint and the Envirotex Design platform [9], which addresses both process and product aspects. With the exception of the Higg Index, which is fully supported by an Association, all the other ones developed within cooperation programs have limited long term deployment and support.

## 3. Computer-Aided Engineering in the footwear industry

CAE in footwear design is limited to virtual performance evaluation (mechanical, thermal, comfort, etc) for an intended use and virtual optimization, in which key parameters (topological or material properties) are determined to achieve certain product performance. Footwear CAE takes place at either component or final product level. CAE for solid industrial components (e.g. heels, toe caps), that are normally inputs to the footwear industry, follows standard mechanical analyses practices and will be no further considered. With regard to textiles and leather, several analytical models, stochastic models, neural networks and other techniques exist [9]. Although useful for guiding material selection, these concern the performance of materials in flat form. However, footwear products have complex 3D topology and multi-material structure. Techniques such as multivariate analysis and Finite Element Analysis (FEA) have been applied on sole, upper and full footwear level for assessing performance of plantar pressure distribution, shock absorption, bending and torsion characteristics, upper pressure on the foot, upper fitting, plantar fitting, thermal and vapor exchange characteristics [9], [14].

FEA is suitable for problems, with complex loading and boundary conditions, involving the interaction of several multi-material solids with complex geometries, such as the footwear-foot-ground system. The availability of accurate biomechanical information on human motion and digital foot biomodels are fundamental to the application of FEA in footwear [15], [16]. Deploying FEA requires a high level of expertise; however, once the analyses are parameterized and standardized, then it is possible for non-experts to apply the techniques. This approach was used in the Optshoes project [17] for determining footwear comfort characteristics, where a simple to use web-based interface limits interactivity to parameterization of input files without any further involvement with the underlying FEA kernel [7]. The entire process is facilitated by using a specialized Material Database.

#### 4. Integrating Computer-Aided Engineering and Material Selection in modern footwear design

Computer-aided engineering and material selection are transforming services that support engineering aspects of product development. These follow the stages of conceptualization, concept screening and preliminary design. The footwear industry is gradually moving towards the application of product engineering practices [9]. These are not just value adding but increasingly important elements of the value chain. Depending on the knowhow and infrastructure of the firm concerned and the economics of the process, design can either be an internal function or outsourced to specialists [18]. Large sports and technical footwear enterprises and smaller niche manufacturers of customized solutions often invest in specialized product engineering infrastructure. In these sectors the value of product development is significant. Owning the CAE functions ensures strict control of them, as well as quick response and flexibility of the CAE “service” to emerging market demands. When the intensity and value of product engineering activities are lower, then it makes business sense to outsource the whole function or part of it. In this case, the company has to avoid any adverse effects on the dependability on design. It has to ensure acceptable quality and timeliness of the outsourced design service and reasonable flexibility to emerging demands with all partners involved. In addition, any outsourcing has to be cost effective and meet budgetary requirements.

The strategic importance of design will continue to rise [3] and so will the need for dependability on its outsourced functions. A question of how to best deploy outsourced functions given the current state of technological progress, thus, arises. Inter-organizational deployment of CAE and material selection software that overcome limitations on design transforming resources is increasingly feasible through advances in engineering design technology and this facilitates outsourcing. Modern solutions now support collaboration, access to data on multiple sites and enhanced remote 3D visualization across different platforms. However, they require thorough and integrated development of both system architecture and software, with the latter exploiting advances in remote visualization, communication and distributed geometric computing algorithms [6], [7]. The aim of these is to overcome the key non-functional limitations of collaborative CAD/CAE systems: performance, usability, and scalability. Today, the realization of collaborative 3D visualization and access to multisite databases is taking place over the web. CAD/CAE inevitably follow wider trends in the IT Industry which is evolving around an Internet-based service model, according to which most end users receive services on demand, irrespectively of their location and means of delivery. Cloud computing seems to have evolved to the main tool for realizing this model, through external hosting of intensive processing and storage functions and delivery of software-based services to end users over the Internet [7]. It reduces client-side hardware and software requirements, as well as complexity and is appropriate for outsourcing processing power and storage. In the case of CAD/CAE, which is specialized service offered by specialist providers, the cloud service model of managing Software as a Service (SaaS) appears to be a promising manufacturing option. The concept of Software as a Service allows for quick deployment of necessary software updates and changes, access to specialized IT functions and takes the burden of hardware installations, system upgrades and maintenance off the client [7].

The question of whether to deploy fat or thin client configuration in order to deliver CAD/CAE as a Service is a critical one. Though fat client configurations may be feasible and cost effective for companies with extended and intensive footwear development activities, supported by all necessary hardware and the state of the art in design software, this is the exception rather than the rule. The reality for most manufacturers is that CAE is a peripheral activity and product development facilities and staff are not geared towards fully supporting it. Thin client visualization configuration, on the other hand, allows for resource intensive computations and rendering performed at remote specialized servers with only minimum processing taking place at the client’s end. However, footwear manufacturers considering thin client options, have to take into account adverse effects on model quality, reduced speed of rendering, 3D content latency, limitations on interactivity, as well as issues regarding proprietary or open technologies. In fact, there are still several compatibility problems between different platforms utilizing various plug-ins and multimedia APIs, for some of which license fees are required. It is expected that the adoption of the new WebGL for graphics and HTML 5 for

website applications will gradually leverage modern systems from such legacy issues [7]. With regard to improving 3D content latency, formats such as VRML, X3D, W3D and MPEG-4 have contributed to the emergence of innovative and faster CAD/CAE file exchange approaches [7]. In order to improve the performance of the thin client approach, the concept of the ‘Balanced Client-Server’ can be incorporated, where intensive data and visualization processing is taking place at the server close to the data, while final visualization and rendering are performed by the client. The key features of the aforementioned approaches are listed in Table 1.

A paradigm of CAD/CAE cloud-based deployment as a service, through the balanced client-server approach, for estimating the comfort parameters of footwear designs was developed recently [7], [17]. In this implementation, data management and processing take place at Cloud-based servers and the clients are only provided with simulation results. Through the development of a model-view-controller pattern, the end-users (typically footwear designers and specialists) do not need to engage in FEA tasks (i.e. pre-processing, boundary conditions), since the web-based interface allows for easy parameterization. In addition, licensing issues for CAD/CAE software are not the responsibility of the end-user but of the service provider. This minimizes service costs for the designer/manufacturer.

**Table 1.** Key features of fat, balanced and thin client-server configuration.

	Level of processing	Infrastructure	Interactivity
Fat Client	Most visualization, rendering and display data at client’s side.	Heavy for graphics processing Increased network bandwidth.	Very high.
Balanced Client	Data intensive visualization and rendering on server. Final rendering and display on client.	Sufficient accelerated graphics units and software plug-ins.	Moderate.
Thin Client	Visualization and rendering processing on server. Only imagery sent to client.	The minimum of modern display arrangements.	Only pre-processed images displayed.

The deployment of CAD/CAE as a Service on demand, utilizing cloud computing, through ICT infrastructure typically found in modern footwear enterprises is therefore considered practically feasible. The end users do not need to be specialists to use key CAE and material selection services, heavy processing tasks are performed at the server side and the solutions have reasonable cost. In addition, with regard to material selection software, providers have come up with innovative modular offers, using cloud computing for managing queries taking the burden of operating extensive material databases and intensive query tools off the clients.

With regard to human resources, it is still important that key professionals understand the concepts and phenomena involved, are able to parameterize their design problem, understand the basic concepts of CAE tools and interpret the simulation results. The role of relevant training is essential in order to equip designers with new tools for developing competitive products in the footwear sector. International cooperation initiatives, such as [19], can be utilized to successfully provide training modules to the footwear industry in order to cope with the modern product design demands.

**5. Conclusion**

The options for integrating CAE and computer-assisted material selection in modern footwear design were investigated considering their Value Chain position and the state of the art in technology available for the sector. The key finding is that advances in cloud computing are making deployment of footwear CAD/CAE as a Service feasible. Further improvements of this approach are expected through disengagement from legacy plug-ins and APIs, as well as overcoming 3D content latency issues, as new development tools (WebGL, HTML5) and formats (VRML, X3D, W3D and MPEG-4) become widely adopted. The paradigm of managing CAD/CAE as a Service allows for companies to outsource intensive aspects of CAD/CAE functions with minimum costs. Cloud computing options, as well as modular options and flexible pricing offers have also contributed to the proliferation of

computer-aided material selection in industry. For both CAD/CAE and material selection functions, footwear manufacturers can now deploy them as outsourced services, while maintaining high quality of the results, adherence to timeframes, flexibility to emerging demands and low cost, thus, ensuring high business dependability on the design process.

## References

- [1] Kotler P and Keller K L 2016 *Marketing Management* 15th edition (Pearson)
- [2] Ease M 2009 *Fashion Marketing* 3rd edition (Wiley-Blackwell, Oxford)
- [3] Muratovski G 2015 Paradigm Shift: The New Role of Design in Business and Society *She Ji: The Journal of Design, Economics, and Innovation* doi:10.1016/j.sheji.2015.11.002
- [4] Slack N, Brandon-Jones A and Johnston R 2016 *Operations Management* 8th edition (Pearson)
- [5] Eckert C and Demaid A 1997 Concurrent Engineering *Proc. of 78th International Conference of the Textile Institute* May 1997 Thessaloniki Greece
- [6] Turban E, Volonino L and Wood G 2013 *Information Technology for Management: Advancing Sustainable, Profitable Business Growth* 9th edition (Wiley)
- [7] Zissis D, Lekkas D, Azariadis Ph, Papanikos P and Xidias E 2016 Collaborative CAD/CAE as a Cloud Service *International Journal of Systems Science: Operations & Logistics* **4:4** 339-55 doi:10.1080/23302674.2016.1186237
- [8] Křemenáková D, Mertová I and Kolčavová-Sirková B 2008 Computer-aided textile design 'LibTex' *Indian Journal of Fibre & Textile Research* **33** 400-4
- [9] Azariadis P and Papagiannis P 2010 A new business model for integrating textile/clothing and footwear production *Proc. of the 3rd International Conference on Advanced Materials and Systems – ICAMS 2010* Bucharest September 16-18 2010 235-40
- [10] Islam M and Khan M R 2014 Environmental Sustainability Evaluation of Apparel Product: A Case Study on Knitted T-Shirt *Journal of Textiles* <http://dx.doi.org/10.1155/2014/643080>
- [11] SHOELAW LIFE08ENV/E/000147 project *Promotion of Environmental Legislation among European Footwear Industries* available at [http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n\\_proj\\_id=3438](http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n_proj_id=3438)
- [12] SHOEBAT LIFE12ENV/ES/000243 project *Promotion of best available techniques in the European footwear and tanning sectors* available at [http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n\\_proj\\_id=4621&docType=pdf](http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n_proj_id=4621&docType=pdf)
- [13] CO2SHOE LIFE12ENV/ES/000315 project *Footwear Carbon Footprint* available at <http://www.co2shoe.eu/en/>
- [14] Papagiannis P, Koutkalaki Z, Azariadis P and Papanikos P 2015 Definition and Evaluation of Plantar Mechanical Comfort for the Support of Footwear Design *Computer-Aided Design and Applications (Taylor & Francis) Special Issue: Technologies for Human Centric Free-form Products* <http://dx.doi.org/10.1080/16864360.2015.1084189>
- [15] Papagiannis P, Koutkalaki Z and Azariadis P 2014 Footwear plantar mechanical comfort: Physical measures and modern approaches to their approximation *Proc. of the 5th International Conference on Advanced Materials and Systems* Bucharest October 23–25
- [16] Azariadis P 2012 Finite Element Analysis in Footwear Design *The Science of Footwear* ed Goonetilleke R (Taylor & Francis Group) 321-37
- [17] OPTSHOES project *Development of cost-effective and accurate computer-aided design and engineering (CAD/CAE) tools for the determination and optimization of footwear comfort parameters* available at <http://optshoes.syros.aegean.gr>
- [18] Porter M 1998 *Competitive Advantage: Creating and Sustaining Superior Performance* (The Free Press, New York)
- [19] Erasmus+ project 2015-1-RO01-KA203-015198 *Knowledge 4 foot - Knowledge Platform for Transferring Research and Innovation in Footwear Manufacturing* final report