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Innovation toolkit for Identification of the Optimal Module Options in Open Platform Architecture Products

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Abstract

Open platform architecture products (OPAP) are the key enablers for Product design for Mass Individualisation. It is a new product design paradigm that comprises an open hardware platform, mass-produced by large manufacturers and multiple independent modules, invented and produced by other smaller companies and by the end-user that are integrated with the platform. It gives freedom to end-users to integrate different modules into the platform as per their choice. This type of product integration will be engaged with by the all actors involved in the design and aims to help them to be more creative and innovative. The end product will be highly individualised and technologically advanced.

Based on explorative literature analysis, with practical insights from an industrial questionnaire survey, an Innovation toolkit for the end-user has been developed. The Innovation toolkit provides a mean of selecting an optimal module option for each module which will be integrated on the hardware platform. The design of the Innovation toolkit for OPAP has been approached in three different steps: Modelling of OPAP, Modelling of evaluation measures and evaluation indices with end-user preferences and Identification of the optimal module options. In this work, variations in module options for a given module are modelled by an AND-OR tree and parameters of the nodes in this tree. Different module options for the selected module are evaluated by various evaluation measures. These evaluation measures are converted into comparable customer satisfaction indices. The optimal OPAP is identified by constrained optimisation of the overall customer satisfaction index. Two case studies have been presented to demonstrate the effectiveness of the introduced Innovation toolkit. These case studies illustrate that the Innovation toolkit can readily be applied to these types of product development to obtain a highly individualised OPAP with optimised module options.

Keywords: Design optimisation, innovation toolkit, mass individualisation, open platform architecture products.

1 Introduction

Industrial product design has changed significantly over time. These changes tend to be initiated either by market conditions or the consumers' desire for the product offering. With the industrial revolution, the idea of individually crafted designs was replaced by product design for mass production, followed subsequently by product design for mass customisation. Mass customisation aims at customisation of products and services for customers at a mass production price and efficiency (Mitchell M. Tseng & Jiao, 2001). Traditionally, most products are designed by professionals working for the underlying firms in design teams because those people “have acquired skills and capabilities that allow them to perform most design tasks more effectively and at a higher level of quality” (Ulrich, 2011). However, a significant shift has been observed over time, with technological advancement. Innovation technologies (IvT) (Dodgson, Gann, & Salter, 2005) have facilitated new strategies for product design and development. New technologies have democratised the tools for both invention and production (Anderson, 2012). Anyone with an idea can use advanced and accessible technologies and turn it into a product.

Concurrently, the user has started to contribute in the design process with professional design teams. Certain users are able and motivated enough to share their innovative ideas with firms. This idea of user participation is not new and has been documented extensively (Von Hippel, 2005). Ninan and Siddique (2006) proposed configuration tools to optimise and assess the feasibility of customer choices. By considering customers as both individuals and as an integral part of the design process, inherent characteristics such as personal taste, innate needs and experience become integral parts of product design (M. M. Tseng, Jiao, & Wang, 2010). The growing saturation of the markets and continuously increased aspiration level of customers are the primary drivers for the development of customer individualised products (Holle & Lindemann, 2015). These products draw on a new set of strategic decisions related to how value is created and captured, how the relationship with conventional business partners such as suppliers are redefined, and what role organisation should play as industry boundaries are expanded (Porter & Heppelmann, 2014). The net effect of these products on industry structure will vary across industries, but different perspective can be categorised. Kumar (2007) has documented the strategic transformation from mass customisation to mass personalisation. However, recent changes in user aspirations and inclination towards more individualised product offering have motivated innovators and product designers to approach a new paradigm. Our research aims to investigate and develop one such product design paradigm, known as Product design for mass individualisation (MI). Explorative literature analysis and practical insights from an industrial questionnaire survey, conducted among consumer product companies, shows that end products in MI are highly individualised and technologically advanced (Sikhwal & Childs, 2017).

Although MI has been considered a promising industrial product design paradigm to meet the increased aspiration level of today's end-users, it also faces many challenges due to multi-dimensional variations of end products. To model these variations and capture innovation from different actors, a systematic approach and tools are required. Different constraints from so many actors have to be taken into account while solving these models. Xie, Henderson, and Kernahan (2005) developed modelling for engineering product configuration problems and solved them by constraints satisfaction. Once the modelling of these individualised products is done, the next step is to identify the optimum configuration with optimum module options. Hong, Hu, Xue, Tu, and Xiong (2008) used genetic programming and parameter based optimisation to identify the optimal product configuration and its parameters for one-of-a-kind (OKP) production. In this paper, an Innovation toolkit is presented to optimise module options for a given module.

2 Product design for Mass Individualisation (MI)

Product design for MI is based on open platform architecture products (OPAP) that comprises of an open hardware platform, mass-produced by large manufacturers and multiple independent modules invented and produced by other smaller companies. The open hardware platform is integrated with different modules as per end user's needs. Modules are selected using the interactive design program. Thus the end product, which fits the exact requirements of the customer, is highly individualised. This paradigm is named "Mass Individualisation" as products are mass produced, but each one is tailored to the needs of the individual buyer (Koren, Hu, Gu, & Shpitalni, 2015).

The design is approached through the formulation of a product ecosystem considering platform producers, 3rd party module vendors and end-users. The prevailing practice of individualisation is to identify exact customer needs with full involvement. A product ecosystem can be specified as a network of different actors involved in the design with the support of technical and business system, along with the customer interaction interface. Figure 1 illustrates the simplified version of the Ecosystem for MI (Sikhwal & Childs, 2017). In the developed framework, it is envisaged that large manufacturers will provide the platform of the product along with interfaces for adding modules. These interfaces/modules can be satisfied by different module options. Limited numbers of specific module options will also be provided by the platform producers for some very particular functions of the end product. Smaller companies/3rd party module vendors will invent and produce modules options for the end-users to use and to integrate into the platform. Different module options will have different parameters to fulfil the requirement of the selected module by the end-users. Thus the basis of competition shifts from discrete products to modules and product systems consisting of interfaced modules or module systems on the product platform.

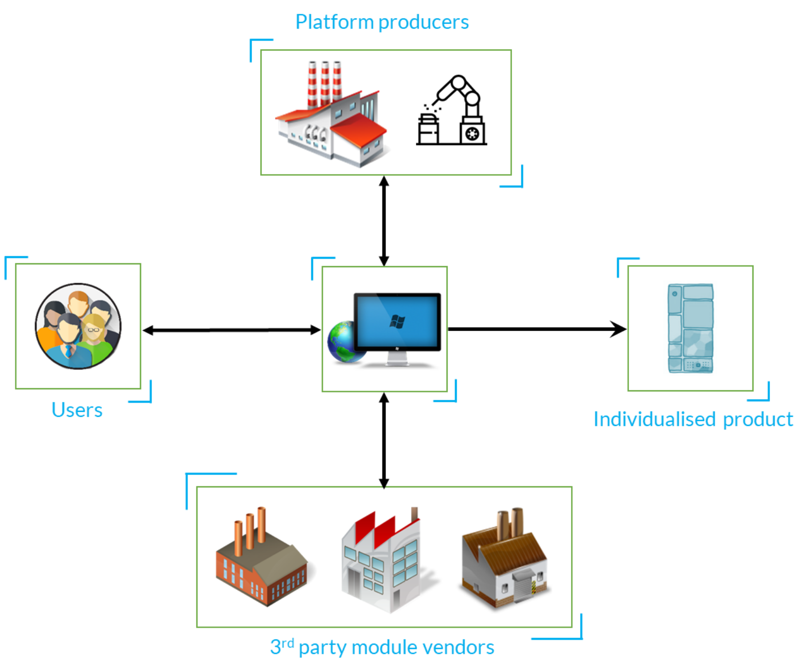


Figure 1 Mass Individualisation (MI) ecosystem

The cross-connection between different actors involved in the design process of MI requires new creative and innovative approaches. It requires changes in the way traditional industrial product design and innovation are approached. An explorative study of existing product design and customisation approaches has been conducted in earlier work (Sikhwal & Childs, 2017).

Based on this study an industrial questionnaire survey was conducted for industrial insights from the companies working in the area of industrial product design. This feedback was used to develop the understanding of the product design for MI further. As mentioned in the previous section, MI is a development on the existing user-centric customisation and personalisation approaches for product design. The variability that MI creates in traditional product design, end-user needs, regulations from different authorities and standards can be challenging. Given the benefits MI provides to all the actors, these challenges are worth addressing. As our earlier work suggests, MI will be beneficial in a range of markets, but consumer electronics and furniture markets are well-known sectors that can be benefitted more from end-users' perspective. MI with OPAP can be implemented in various products like smartphones, smartwatches, individualised furniture.

2.1 Open platform architecture products (OPAP)

Open platform architecture products (OPAP) are the key enablers for Product design for MI. OPAPs are based on an open hardware platform with many interfaces for module integration. Figure 2 illustrates an OPAP skeleton with interfaces, specified module options and unknown module options. It is a typical schematic representation of open platform architecture products.

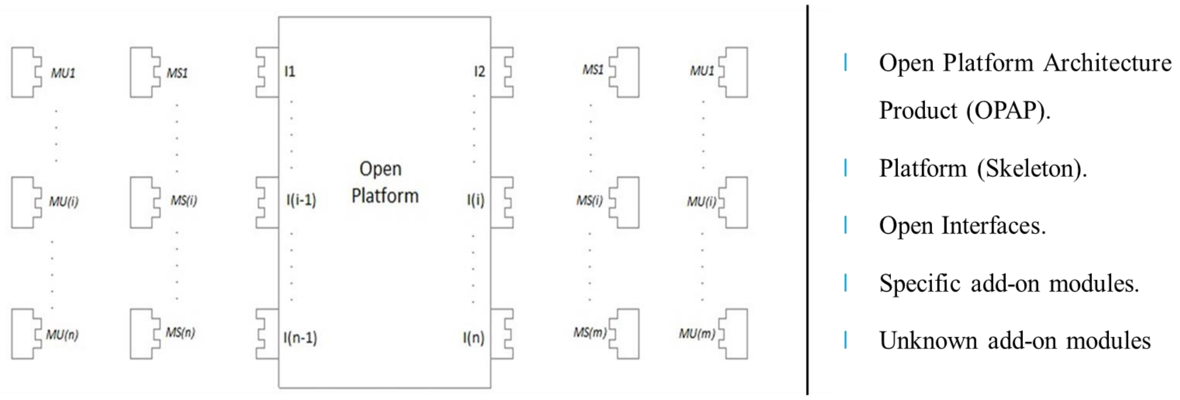


Figure 2 Schematic representation of an OPAP with platform, interfaces and module options

The platform is specified as the Skeleton in our research work. Specific module options show the modules which can be selected at the time of first use of the product by the end-users, where unknown module options demonstrate adaptability or those modules which can be added in future as per users change in requirement. Interfaces are represented by ‘I’ (1, 2, 3……..n). Specific module options are represented by ‘MS’ (1, 2, 3……..n, and 1, 2, 3……m), and unknown module options are represented by ‘MU’ (1, 2, 3……..n, and 1, 2, 3……m). In this work, only specific module options are the primary focus for the development of the Innovation toolkit.

2.2 Innovation toolkit for OPAP

A networked Innovation toolkit describes a design environment which enables actors to formulate their requirements iteratively and transfer these into a producible solution by an iterative process with continuous live networked support from other actors in the OPAP ecosystem. The function of one module or module system can be optimised with other related modules or module systems with this Innovation toolkit. The initial idea is to develop a multi-level optimisation model for this Innovation toolkit to identify the best design configuration with optimal module options which satisfies all the requirements of the end-user. Figure 3 depicts the approach for multi-level optimisation for networked Innovation toolkits, based on the five phases of design for open Innovation (Holle & Lindemann, 2015).

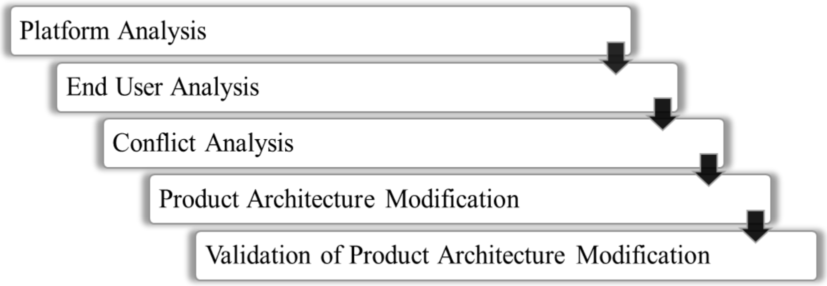


Figure 3 Different phases of Innovation toolkit

1. **Platform Analysis -** This phase consists of an analysis of product type and category which provides the basis for analysis of the required platform with a required number of interfaces.
2. **End-user Analysis -** Acquisition and interpretation of individualisation wishes, and derivation of modules and interfaces which is required for individualised products.
3. **Conflict Analysis -** Determination of individualisation potential based on weighted criteria, and derivation of alternative scenarios from end-users, modules manufacturer and platform manufacturer. This phase is the basis for determination of constraints for multi-level optimisation model.
4. **Product Configuration Modification -** Definition of Alternative Product Configurations, Assessment of Alternative Product Configurations, and Selection of suitable Product Configuration with an optimised combination of modules interfaced with the platform.
5. **Validation of Product Configuration Modification -** Validation and Feedback for iterative improvement of product configurations from the end-user.

Design of an Innovation toolkit for OPAP has been approached in three different steps: Modelling of OPAP, Modelling of evaluation measures and evaluation indices with end-user preferences and Identification of the optimal module options. Based on the design of adaptable products (Martinez & Xue, 2017), a framework is developed considering different design configurations and for an overall satisfaction index for optimisation of the same.

The following assumptions are used for the development of the model:
- Adaptability and cost of the all feasible configurations with different module options are comparable.
- The Primary requirement of the customers can be represented by the module options of each module/interface, and it is only allowed to configure a product that offers higher-order module options than the customer requirements.
- The end-user acts as a lead to decide on the platform and module supplier selection.

3 Modelling of OPAP

The end product is a result of participation from many module option suppliers and the end-user himself/herself. This multi-directional participation causes many variations in the end product. These variations include two kinds of variation: variation of configuration and variation of parameters. As the same type of module would be provided by different 3rd party vendors, known as module options, the probability of variation of parameters is high. For a selected OPAP platform (skeleton), different modules will be selected by the end-user as per their choices. After selecting particular modules for skeleton interfaces, the second choice will be to select module options in terms of desired parameters for modules. So a new method to model the variations of OPAP product configuration and the variations of product parameters in terms of module options is required to be developed. This paper deals with the second part, i.e. variations in the module options.

Excessive variety might lead to problems in the design and manufacturing of products, so-called “mass confusion” (M. M. Tseng & Piller, 2003). Compared with the traditional product customisation approaches, the variation of configuration and parameters is too high in product design for MI. Therefore, a sophisticated automated Innovation toolkit is required for modelling of OPAP product with variations. For the automation of the modelling, the different product configurations are modelled by an AND-OR tree in this work. The product structure (OPAP skeleton) in OPAP can be decomposed into different sub-structures (module/interfaces), connected with an AND relation. Every sub-structure can be satisfied with different module options, and these module options are associated with an OR relation. Each module option in the AND-OR tree is further modelled in terms of parameters. These module options parameters include continuous parameters (e.g. dimensions of modules), integer parameters (e.g. a number of sub-module) and Boolean parameters (e.g. true or false for any particular module option).

Figure 4 shows the variations of an OPAP modelled by an AND-OR tree. The variations of configurations can be illustrated by combinations of different module options with different interfaces, selected by the end-user as per individual needs. A feasible individualised OPAP can be obtained from the AND-OR tree through a tree-based search (Russell & Norvig, 2002). In this work, the following conditions are used to generate different feasible design configurations:

1. The first node should be the root node, to be selected.
2. After selecting the root node, all the sub-nodes should be selected, if all its sub-nodes are connected with an AND relation.
3. After selecting the root node, only one of the sub-nodes should be selected, if all its sub-nodes are connected with an OR relation.

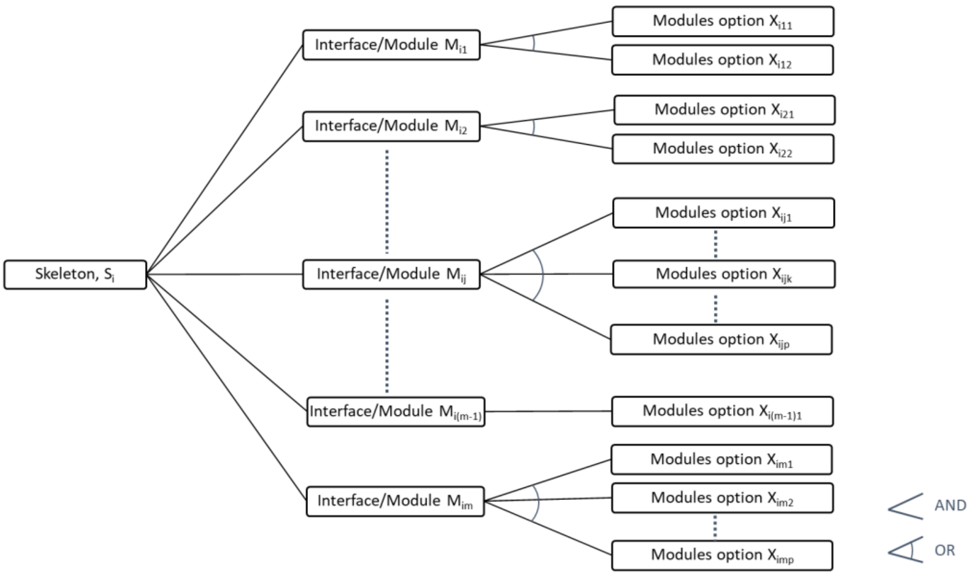


Figure 4 AND-OR Tree diagram for modelling different OPAP Configuration

If a module node for the i[th] design configuration S_i (i=1, 2,…..n) is defined by M_{ij} (j=1, 2,….m). This design configuration can be described as follows:

$$S_i = (M_{i1}, M_{i2} \ldots\ldots M_{im}) \ , \ i = 1, 2, 3, \ldots\ldots n \quad (1)$$

A module node is associated with the different module options nodes. These module option nodes represent different design parameter choices for a particular module node. The k^{th} design parameter X_{ijk} of the module node $M_{i.j}$ is defined in the form of $M_{ij}.X_{ijk}$. Therefore the parameters of a module node, Mij, can be described as follows:

$$X_{i,j} = \left(M_{ij}.X_{ij1}, M_{ij}.X_{ij2} \ldots..M_{ij}.X_{ijk}\right)\ ,\ i = 1,2,3,\ldots\ldots.n,\ \text{and}\ j = 1,2,3,\ldots..m \quad (2)$$

The parameters for the i^{th} design configuration considering all involved nodes are defined by

$$X_i = (X_{i1}, X_{i2} \ldots..X_{ik})\ ,\ i = 1,2,3,\ldots\ldots.n \quad (3)$$

The complete design solution of this configuration can be then defined,

$$D_i = (S_i, X_i)\ ,\ i = 1,2,3,\ldots\ldots.n \quad (4)$$

If only i^{th} design configuration is considered in terms of parameters, then

$$S_i = \left(X_{i1}, X_{i2} \ldots..X_{in_i}\right) \quad (5)$$

4 Modelling of evaluation measures and evaluation indices with end-user preferences

OPAP provides different product configurations based on the individual requirements from the individual end-user. Different product configurations are evaluated by customer satisfaction measures and indices.

4.1 Evaluation measures

An evaluation measure can be either a constant, a monotonic function of life cycle time, T, (i.e. increasing function or decreasing function), or a non-monotonic function of life cycle time, T. For this research work, these measures can be classified into two categories: performance measures and cost measures. Performance measures include efficiency, speed, resolution, etc., whereas cost measures include product cost, module replacement cost, maintenance cost, etc.
For a product configuration, S, with n parameters, evaluation measure in the i^{th} evaluation aspect (measure) is defined by,

$$E_i = E_i(X_1, X_2, X_3, \ldots\ldots.X_n) \quad (6)$$

In this research, performance measures are denoted by P_i, and cost measures are denoted by C_i.

4.2 Evaluation indices

Different evaluation measures are in different units, so these evaluation measures need to be converted into comparable evaluation indices between 0 and 1, which represents different levels of satisfaction (Yang, Xue, & Tu, 2005). Customer (End-user) satisfaction has been selected as an evaluation index in this work. Different comparable evaluation indices can be integrated to model the overall customer satisfaction index.

4.3 Conversion of evaluation measures into evaluation indices

The evaluation measure and evaluation index can be related by a linear or a nonlinear relation. The evaluation measures can be classified into three categories: the-smaller-the-better, the-larger-the-better, and the-nominal-the-best. However, in case of evaluation index, higher evaluation index indicates a higher satisfaction level.

The customer satisfaction index, in the i^{th} evaluation aspect, is defined by,

$$CS_i(X) = F_i[E_i(X)] \quad (7)$$

where i= 1, 2, 3………m

After converting all the customer satisfaction indices into comparable measures, these m indices can be described by values in between 0 and 1. By considering the importance of these evaluation measures, overall customer satisfaction index, CS, can be defined as follows:

$$CS(X) = \frac{1}{W_1+W_2+W_3+\ldots\ldots+W_m}[W_1CS_1(X) + W_2CS_2(X) + W_3CS_3(X) + \ldots\ldots.+W_mCS_m(X)] \quad (8)$$

where W_1, W_2, W_3,…….,W_m are m weighting factors for m evaluation indices.

These individual weighing factors are selected by the end-users according to their individual requirements and preferences. Other methods to identify the weighing factors of different evaluation measures have also been developed in the literature. One of such method is pair-wise comparison method is developed by Saaty (1980). The relation between an evaluation measure, $E_i(X)$ and its evaluation index, $CS_i(X)$, could be in the form of discrete points or a continuous function. If it is in the form of discrete points, then this relationship has to be converted into a continuous function relation as a continuous function is required for optimisation. To identify this continuous function from discrete points, the least-square curve-fitting method (Hoffman, 2001) is used. By having the value of all evaluation indices between 0 and 1, overall customer satisfaction index can be evaluated by the equation (8).

5 Identification of the optimal module options

Since a large number of design configuration with different module options can be selected to fulfil the individualised requirement, optimisation is employed to identify the best design configuration with optimal module options. A constrained optimisation model is employed in this work to identify the best design configuration solution with optimal module options. In this optimisation model, the optimal module options for the i^{th} design configuration solution are achieved through parameter optimisation. This optimisation is to be undertaken to achieve i^{th} configuration, which optimises the satisfaction of the end-user requirements. The same Innovation toolkits can be expanded and customised for other actors such as smaller companies. This can be summarised as follows:

- **Objective function:** To find the i^{th} design configuration with optimised module options.
- **To optimise:** Satisfaction of the end-user requirements will be maximised from the design configuration within the constraints provided by other actors of the OPAP ecosystem. Certain parameters will be defined to measure the end-users satisfaction from the given design configuration.
- **Constraints:** Large manufacturer, responsible for the manufacturing of the platform and interfaces, will define some constraints including functional, safety and assembly constraints. Smaller companies providing the module options will also provide some constraints based on their manufacturing capability, spatial and other constraints.

After evaluating different product configurations with different module options by the overall customer satisfaction index, product configuration can be optimised by optimisation model. The overall customer satisfaction index can be considered as the optimisation objective function. It can be defined by the average-case method in which the average evaluation index is used as the objective function for parameter optimisation considering one design configuration. The average-case method is generally the most suitable for the optimal design of OPAP. In this work, module option optimisation is done with penalty-based optimisation (Arora, 2016) method. In the presence of constraints provided by different actors, penalty functions are used to convert a constrained optimisation problem into an unconstrained optimisation problem. The optimal parameter values for a product configuration, S_i, defined by its parameters $(X_{i1}, X_{i2} \ldots\ldots X_{in_i})$, using constrained optimisation approach, can be obtained as follows:

$$\underset{\text{wrt } X_{i1}, X_{i2} \ldots\ldots X_{in_i}}{\text{Max}} \; CS(X_{i1}, X_{i2} \ldots\ldots X_{in_i}) \tag{9}$$

Subject to:

$$X_{ij}^{L} \leq X_{ij} \leq X_{ij}^{U}, \qquad j = 1, 2, 3, \ldots \ldots . n_i \tag{10}$$

$$h_{ij}(X_{i1}, X_{i2} \ldots\ldots X_{in_i}) = 0, \qquad j = 1, 2, 3, \ldots \ldots \ldots \ldots k_i \tag{11}$$

$$g_{ij}(X_{i1}, X_{i2} \ldots\ldots X_{in_i}) = 0, \qquad j = k_i + 1, k_i + 2, \ldots \ldots \ldots \ldots m_i \tag{12}$$

Such a constrained optimisation problem can be converted into a non-constrained optimisation problem by adding a penalty term to the objective function mentioned in the equation (9). The modified objective function with a penalty term can be defined as follows:

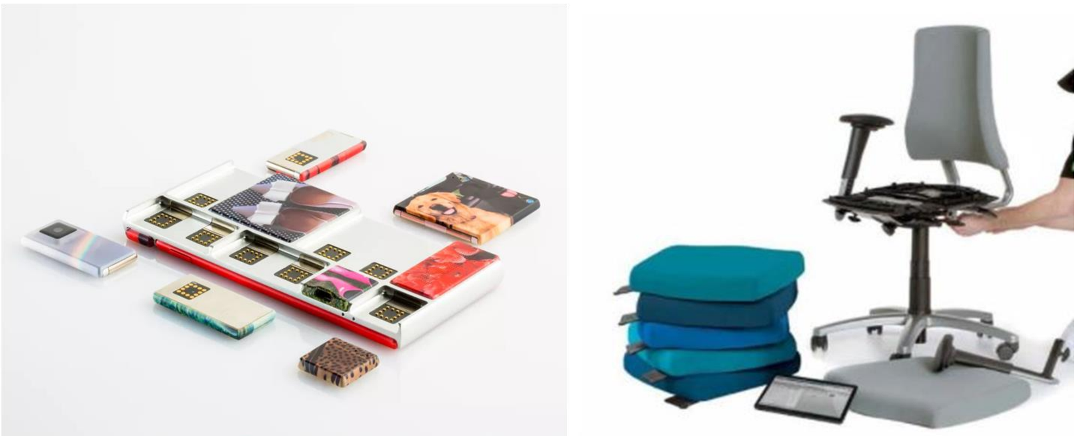
$$UCS_i(X_{i1}, X_{i2} \ldots\ldots X_{in_i}) = CS_i(X_{i1}, X_{i2} \ldots\ldots X_{in_i}) - \varphi . p_i(X_{i1}, X_{i2} \ldots\ldots X_{in_i}) \tag{13}$$

where, UCS_i represents the non-constrained form of CS_i, $p_i(X_{i1}, X_{i2} \ldots\ldots X_{in_i})$ is the penalty term for the unconstrained objective function and φ is a multiplier constant that determines the magnitude of the penalty.
The penalty term is defined as follows:

$$p_i(X_{i1}, X_{i2} \ldots\ldots X_{in_i}) = \sum_{j=1}^{k_i} \left[h_{ij}(X_{i1}, X_{i2} \ldots\ldots X_{in_i})\right]^2 + \sum_{j=k_i+1}^{m_i} \left[g_{ij}(X_{i1}, X_{i2} \ldots\ldots X_{in_i}) + \left|g_{ij}(X_{i1}, X_{i2} \ldots\ldots X_{in_i})\right|\right]^2 \tag{14}$$

6 Case studies

The concept of product design for MI can be implemented in the market with a variety of products, but our earlier study suggests that consumer electronics and furniture industries would be a good point to start. This was inspired by the fact that it is easy to adapt OPAP in these industries, both by end-users and module options suppliers. Following this suggestion, a consumer electronics product, OPAP Smartphone (based on Google ARA) and an individualised chair (based on Axia Smart Chair from Nomique) have been used as case studies for our work, as shown in Figure 5(a) and Figure 5(b), respectively.



(a) (b)

Figure 5 Case studies (a) Google ARA, A smartphone based on OPAP (Project ARA by Google, 2016) (b)An individualised chair (Axia Smart Chair by Nomique, 2018)

6.1 An OPAP smartphone (Google ARA)

Information available in the public domain for ARA has been used to formulate the optimisation problem for an OPAP smartphone. Information is gathered from MDK (Modular development kit), a guide for the development of modular technology that Google has provided to developers (Project ARA by Google, 2016). Due to variations of OPAP, selected products are not the optimised one with optimal modules. Once the end-user puts forward the choice for the required module type (e.g. battery module, camera module), different smaller companies will provide different module options (e.g. different capacities for battery, different resolutions for the camera). The variations of this smartphone with different potential module options for four selected modules are shown in Figure 6(a). As the energy requirement for higher resolution camera module option will be higher than for a lower resolution one, battery backup for OPAP with the higher resolution camera module option will be lesser than with later one. For every feasible product configuration, these relations will vary. Hence, the Innovation toolkit will be employed to find the end product which provides a smartphone with optimal module options for the given requirements. A feasible product configuration (not with optimum module options) can be created from this AND-OR tree, as shown in Figure 6(b).

$$S_i = (10MP, 1600\text{mah}, \text{High loudness}, \text{AMOLED}) \tag{15}$$

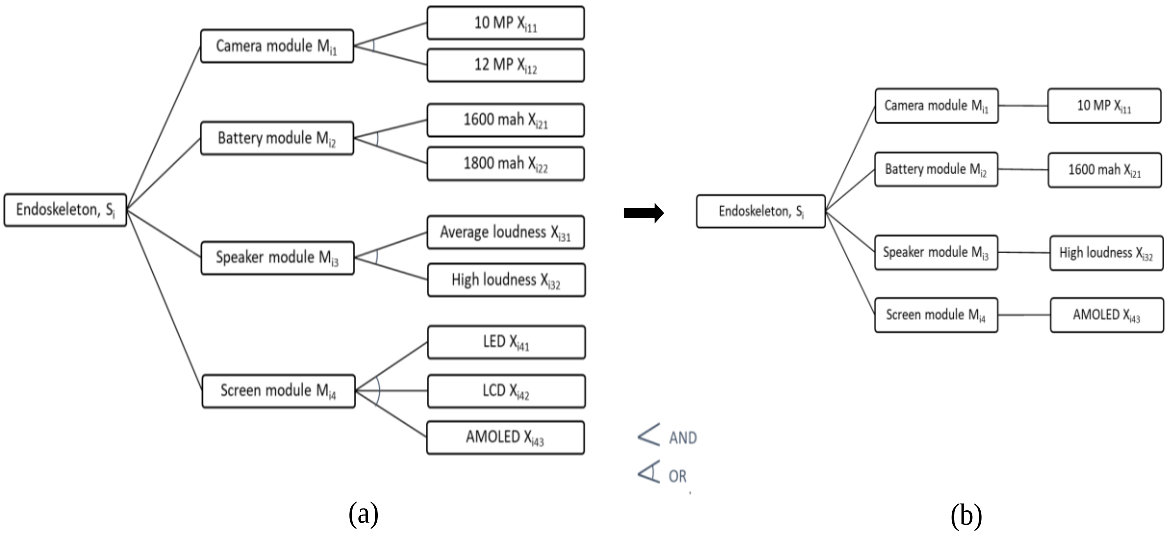


Figure 6 (a) AND-OR tree diagram for OPAP smartphone with different module options (b) A feasible product configuration for OPAP smartphone

Table 1 shows different customer evaluation measures selected for this case study. In this case study, product cost, C_p, is selected as the cost evaluation measure and, weight, P_w, and battery backup, P_{bb}, have been selected as performance evaluation measures. The product cost for different configurations can be determined based on individual cost from different module options suppliers. For weight and battery backup, different correlations in the terms of parameters are used. These three evaluation measures C_p, P_w and P_{bb} are converted into three customer satisfaction indices, I_p, I_w and I_{bb}, respectively. If the weighting factors provided by end-users are x_1, x_2, and x_3 then the overall customer satisfaction index,

$$CS(X) = \frac{1}{x_1 + x_2 + x_3}[x_1 I_p + x_2 I_w + x_3 I_{bb}] \tag{16}$$

This equation will be used for the optimisation of customer satisfaction index with optimal module options' parameters as per equation (9). Configuration satisfying these parameter values gives the best possible candidate for the highly individualised end product.

Table 1 Customer evaluation measures selected for OPAP smartphone

Evaluation measures		Unit	Representation
Cost evaluation measure	Product Cost	GBP (£)	C_p
Performance evaluation measure	Product Weight	Grams (g)	P_w
	Battery backup	Hours	P_{bb}

The end product obtained by this method will have a different configuration for different values of weighting factors for customer satisfaction index, selected by different end-users. In this case study, the number of variations of OPAP is limited to demonstrate the approach. If the number of variations is too high, automated Innovation toolkit can be used. This case study shows that Innovation toolkit developed in this paper will be able to provide a more individualised smartphone, exactly tailored to the needs of every end-user.

6.2 An individualised chair (Axia smart chair by Nomique)

The Innovation toolkit, which is used to obtain an individualised smartphone in case study 1, can be implemented for other individualised end products. Another product, the Axia smart chair from Nomique has been selected as a case study to demonstrate the application of the OPAP and introduced Innovation toolkit. This chair is designed to provide a healthier posture and have a modular system for cushions as shown in Figure 5(b) (Axia Smart Chair by Nomique, 2018).

OPAP with the Innovation toolkit introduced can be used for this kind of smart chair. One large manufacturer can provide the skeleton with smart seating system, and other module options (components or set of components) will be provided by various smaller companies. Once the end-user puts forward the choice for the required module type (e.g. armrest, base), different smaller companies will provide different module options (e.g. different shape and comfort for armrests, a different kind of bases). The variations of OPAP chair with different potential module options can be configured in an AND-OR tree diagram as done for last case study in Figure 6 (a). Due to the significant variation in module options, selected products are not the optimised one with optimal modules. Different evaluation measures, e.g. chair cost, chair weight can be selected for this case study and converted into respective evaluation indices to get the overall customer satisfaction index for optimisation, as done in the first case study. Thus, the end product (smart chair) will be optimised and highly individualised as per end-users needs. This case study illustrates that the framework can readily be applied to this type of product development to obtain a highly individualised OPAP with optimised module options. This case study is presented briefly in this paper just to demonstrate the effectiveness of introduced Innovation toolkit in range of products.

7 Conclusion

An Innovation toolkit for identifying the optimal module options for OPAP has been introduced. Variations in product configurations with different module options in an OPAP are modelled by nodes in an AND-OR tree. The AND-OR with different nodes for module options provides a systematic framework to model large variations of OPAP configurations. Different module options for a selected module are evaluated by evaluation measures and comparable evaluation indices. The optimal module option for every module with maximum overall customer satisfaction index is identified by constrained optimisation. Two case studies are used to demonstrate the applicability of this Innovation toolkit.

Product design for MI is a relatively new area where much research has to be done. To realise and implement this new approach in the market, many issues need to be addressed including optimisation of module option during the product operation stage and development the Innovation toolkit further considering the same. Different monetary aspects, IP rights, acceptance of this approach by existing designers are also need to be tested before implementation in the market.

Acknowledgements

The case studies used in this paper are based on the information available in the public domain about Google Smartphone ARA and Axia smart chair by Nomique. Valuable suggestions from the Dyson School of Design Engineering researchers Liuqing Chen, Ji Han and Feng Shi regarding automation of the Innovation toolkit are also acknowledged.

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