INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED23
24-28 JULY 2023, BORDEAUX, FRANCE

DESIGNING FOR HUMAN FACTORS: DEVELOPMENT AND EVALUATION OF A HARMONISTIC KNOWLEDGE-BASED DESIGN DECISION SUPPORT TOOL

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ABSTRACT

Dual ontological products are a physical construction and an emotional construction. Multitude of human factors must be considering when designing dual ontological products. To increase the product's impact and reach, designers should also understand the requirements of potential users. A design stage conflict exists between the emotional construction and the physical construction of a product when considering human factors. Designers find it difficult to achieve the right compromise between these constructions and hence, the balancing of the two is crucial. This research therefore contributes a novel harmonistic knowledge-based framework which makes designers aware of design stage conflicts and consequences of commitments made on human factors in the use-phase of the artefact. This approach was implemented in a machine learning based computational tool which exploits harmonistic knowledge and information collected from potential users to proactively assist, guide, and motivate product designers. This paper also presents a descriptive study for the evaluation of the framework and its implementation as a computer-based prototype tool. Results show the necessity and beneficial use of the tool for design engineering practice.

Keywords: Computational design methods, Machine learning, User centred design, Concurrent Engineering (CE), Design synthesis

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Cite this article: Agius, S., Farrugia, P., Francalanza, E. (2023) 'Designing for Human Factors: Development and Evaluation of a Harmonistic Knowledge-Based Design Decision Support Tool', in *Proceedings of the International Conference on Engineering Design (ICED23),* Bordeaux, France, 24-28 July 2023. DOI:10.1017/pds.2023.137

1 DESIGN PROBLEM BACKGROUND

1.1 Human factors in product design

Physical products have a dual ontological nature (Kroes, 2001). They are, at the same time, a physical construction and an emotional construction. The physical construct is essential for those products which physically interact directly with humans, whereas the product's emotional construct interconnects with human cognition, where this can lead to stronger brand relationships, increased customer loyalty (Norman, 2013), increased likelihood of repeat purchases (Schmitt et al., 2015) and recommendations to others (Hassenzahl, 2010). Wearable products, or products which physically house humans, such as motorcycles, are good examples of dual ontological products. The customer's perception of these products relies on the balance of both constructs. In this research, *Human Factors*, namely, *Ergonomics*, *Aesthetic Emotions* and *Persona* (which define the personality, attitude and product-use context) aspects, formalised as $hf_{\text{E-AE-P}}$, are considered when designing products. In particular, the motorcycle artefact is taken as a case study. However, as will be discussed further on, this research extends beyond the motorcycle domain.

The physical abilities of human beings vary according to their physical dimensions. The great diversity in these static measures implies that there can be no image of an "average" human and that compromises must be made (Bakshi and Gupta, 2014). Fitting a human to a product leads to a bad ergonomic application. Human beings are comprised of different personality types. A clear understanding of personality and cognitive styles can be helpful in designing products for a specific community of users (Bakshi and Gupta, 2014). Schmitt et al. (2015) and Hancock *et al.* (2006) argue that humans need to be factored in during the product development process, where their voice is directly integrated in the design. The degree to which humans are satisfied with a product correlates with the extent to which the product exceeds, fulfils or disregards the human's visceral, behavioural and reflective levels (Norman, 2013) during the product's life-phase (Schmitt et al., 2015). Farrugia et al. (2019) claimed that product designers have to consider the aesthetic emotional value of products during the design phase, as it has a huge impact on the market success of that product.

1.2 Challenges in designing dual-ontological products

According to Blessing and Chakrabarti's (2009) research methodology, the *first Descriptive Study* concerns with understanding the design problem. A study was conducted by Agius et al. (2020) where in-depth interviews were carried out with eight expert motorcycle designers. Qualitative analysis is exploratory in nature and coupled with literature aided in understanding the challenges during motorcycle design.

Ensuring a product's level of competitiveness requires the satisfaction of customer requirements. The integration of customers into the early stages of design allows for detecting the voice of the customer. Designers stated that this integration should not only focus on potential target customers, but it should have a wider reach to the general riders (Agius et al., 2020). According to Borg et al. (1999), design decisions have consequences when the artefact meets with different life-phase systems of the product, namely design, manufacturing, use and disposal. Thus, during early design activities, designers have to cope with the co-evolution of problems which make it difficult for humans to be aware of them all. As explained by Borg et al. (1999), synthesis decision commitments lead to intended and unintended consequences. Unintended consequences are those consequences that the designer is not aware of when committing to the design decision. It is the unintended type of decision consequence that the designer needs to be made aware of for design guidance.

Motorcycle's aesthetics is manly considered in the conceptual design stage, while ergonomics is considered more in the embodiment stage (Agius et al., 2020). Ergonomics is essential for the comfort and safety of the rider but restrains the whole design, if considered in the conceptual stage. A design stage conflict therefore exists between the physical construction and the emotional construction of the motorcycle when considering human factor aspects. Designers stated that they find it difficult to achieve the right compromise between aesthetics and ergonomics of a motorcycle (Agius et al., 2020). Moreover, to reach as many customers as possible balance between these domains is crucial (Agius et al., 2020). Designers highlighted that it is time consuming to effectively deal with the complexity of the motorcycle design activity. Therefore, they expressed the need and the importance of having a computer-based tool which proactively assists them with their design decisions. Undertaking these

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challenges in the early phases of the motorcycle life-cycle means that cost of design change implementation is greatly reduced (Agius et al., 2020).

In view of these results, it is argued that design supporting computational means for human factors ($hf_{E\text{-}AE\text{-}P}$) is required during product design. Barone and Curcio (2004) proposed a CAD based system for ergonomics analysis of motorcycle scooters during design. This system is able to represent three-dimensional (3D) models of vehicle configurations and equipment, 3D human models of various anthropometries and evaluative techniques to assess reach, postures and assess comfort. Farrugia and Borg (2016) developed a tool based solely on emotions observed during manual assembly of products by operators. During manual assembly, there is an interaction between the operator (user) and the part which has a direct effect on product cost, time and quality. The design support tool developed by Farrugia and Borg (2016) focuses on the manufacturing-phase of the product's life-cycle. The framework presented by Farrugia et al. (2019) is employed to implement a computer-based support tool for the development of sport-bikes. Farrugia et al. (2019) highlighted that the framework is based on facilitating sports-bike designers with knowledge on the riders' elicited emotions to sport-bikes' aesthetics, together with the motorcycle aerodynamic characteristics.

In summary, even though these previous works have contributed towards providing such computational approaches, these provide support late in the design process. Whilst these means further prove the need for supporting human factors ($hf_{E\text{-}AE\text{-}P}$) during product design, this review collectively indicates that there is a gap in assisting designers to concurrently design for ergonomics, persona, and aesthetic emotion aspects early in the design process. Furthermore, none of the support means provides a harmonistic knowledge-based support, which provides a balanced product solution which makes designers aware of design stage conflict and use-phase consequences.

1.3 Research aim

In view of this context, the overall research aim of this study is to develop and evaluate a harmonistic knowledge-based computational approach which provides support during the motorcycle synthesis design activity, in order to minimise or avoid unintentional and problematic human factor use-phase consequences. This knowledge needs to be posed at the right time, not being intrusive to the designer's cognitive activity, and provides a harmonised product solution from a human factor perspective.

2 SOLUTION DEVELOPMENT

2.1 Methodology

In order to achieve this aim, the design research methodologies proposed by Blessing and Chakrabarti (2009), and Duffy and O'Donnell (1999) were adopted to carry out the entire research. The support which is required is primarily derived from the reality, observed from the aforementioned *first Descriptive Study*. Phenomena models are based upon observations and analysis of the reality of design and hence, reflect design practice. Deriving from the first descriptive study carried with motorcycle designers, Agius et al. (2021) have identified two types of consequences generated as result of decision commitments made during the motorcycle synthesis design activity. These are *Population Majority Privation Consequences*, and *Design Stage Conflict Consequences*. The phenomena model is then developed in more detail into an information model, forming a knowledge structure and organised in such a way to form a framework. The computer model is a realisation of the framework as a proof-of-concept. Finally, the evaluation study, presented in this paper, is the *second Descriptive Study* and has been carried out to evaluate the prototype solution. This will investigate the degree of validity and effectiveness of the proposed design framework.

2.2 Harmonistic knowledge-based design framework for human factors ($hf_{E\text{-}AE\text{-}P}$)

In order to provide adequate support to product designers a conceptual framework, illustrated in Figure 1, was developed which takes into consideration the difficulties product designers have in handling interactions that occur between human factor aspects and the evolving product model. The purpose of *DESMO (DESigning MOtorcycles)* framework is to:

- Provide the required support when the integrated solution model is still evolving to help proactively foresee the population majority privation consequences and design stage conflict consequences, whilst providing decision guidance to avoid or minimise these consequences.

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- Provide knowledge, formed from data acquired from users (in this cased motorcycle riders) in a timely manner which will enable designer to consider and explore alternative commitments that will have different impacts on human factors ($hf_{E\text{-}AE\text{-}P}$) during the use-phase of the product's life cycle.
- Guide the designers towards a harmonised synthesis product solution, which balances conflicts occurring between: (i) target users, (ii) general riders, (iii) ergonomics, and (iv) aesthetics.

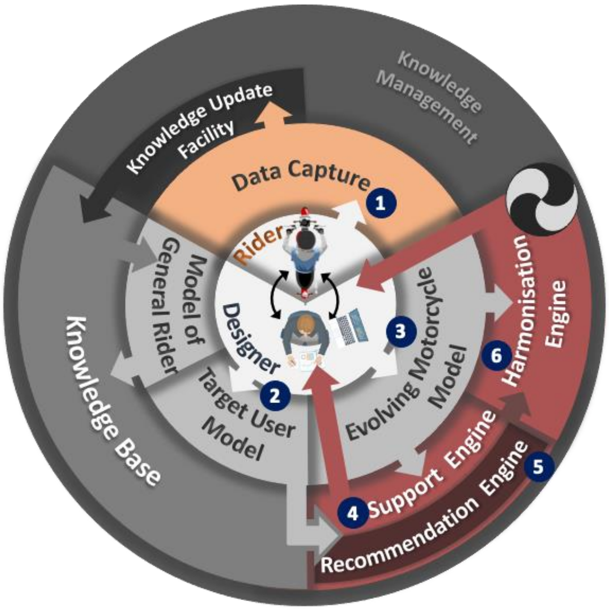

Figure 1. A high-level representation of the DESMO framework

At the core of the *DESMO* framework lie the motorcycle riders. The communication between the potential users and designers is a vital requisite for a user-centred approach. In the first step (STEP 1), the framework captures factual human factors ($hf_{E\text{-}AE\text{-}P}$) information. This information is based on: (i) the rider's anthropometry and ergonomic postures to different motorcycle configurations; (ii) the rider's persona, observed through rider's experiences, personality, age, motorcycle use context and accidents experiences; and (iii) the rider's elicited emotions towards different motorcycle designs, types and styles. Each time an observation is made, the *Knowledge Update Facility* is updated with new observations. In the second step (STEP 2), the designer models the target user for which the motorcycle is intended, while the general rider's ergonomic, persona and aesthetic emotion characteristics are generated automatically by the software, based on the captured data from STEP 1. This entails in the average anthropometric measurements (such as, height or weight) of the population sample, the notable persona characteristics (such as, motorcycle use frequency), and the aesthetic emotion profile that is, what motorcycles and elements the motorcycle riding population sample like the most. The next step (STEP 3) concerns the design synthesis of the motorcycle model. This entails in deciding and selecting design elements from a reusable library to construct the envisaged motorcycle model. From the ergonomics' perspective, the designer decides on the ergonomic measurements of the motorcycle (e.g., handlebar rise, handlebar pullback, seat hight, etc.), and decides on the motorcycle's elements to portray certain aesthetic emotions (e.g., fuel tank / handlebar / seat styles and positions). Once the designer provisionally commits to the synthesised decisions, *DESMO* provides human factor use-phase consequences (STEP 4) via the *Support Engine*. Such support includes the posture of the rider on the evolving motorcycle model, the total ergonomic discomforts, as well as the level of user's/general rider's (dis)liking towards the evolving motorcycle model. This core inference engine uses the necessary knowledge from the *Knowledge Bases* to formulate the consequences and recommendations. The *Recommendation Engine* assists the designer (STEP 5) in exploring other routes to avoid or minimise these problematic human factor consequences. To assist the designer in setting up the motorcycle to better suit the target user / general rider ergonomically and emotionally, the recommendations constitute of the motorcycle measurements leading to minimum ergonomic discomforts. The recommendation engine also proposes what evolving motorcycle elements to change, in order to create a better emotional connected motorcycle model. The

Harmonisation Engine is then utilised to harmonise possible design recommendations (STEP 6) in order to create a provisional balanced solution. Information is gathered directly from the potential design solutions committed up to this point by the designer. To achieve this balance, *DESMO* sets out an objective to minimise the total ergonomic discomforts for the target user and general rider as well as finding the right elements to enhance aesthetic emotions of both target user and general rider. *DESMO* can provide several balanced solutions which are composed of measurements and elements/positions to better suit the ergonomics and emotions of the target user and general riders.

2.3 A computer-based Implementation of the *DESMO* framework

To demonstrate and evaluate the concept of supporting through awareness of consequence knowledge, the harmonistic design approach framework has been implemented as a prototype computer-based tool. A number of aspects relating to how the knowledge is structured, modelled and implemented into a digital design tool are addressed by this prototype, hereinafter referred to as *DESMO-APP (DESMO APPlication)*. The prototype tool system architecture is based on the approach framework illustrated in Figure 1. The tool is modelled on a *Machine Learning Knowledge-Base System (ML-KBS)* illustrated in Figure 2. A *KBS* is a form of *Artificial Intelligence (AI)* that aims to capture knowledge to support decision-making. Contrary to *Rule-Based KBS (RB-KBS)*, *ML-KBS* require a dedicated architecture necessary to extract information from data sources and populate the *KB* (Krzywicki *et al.*, 2016). The presented *ML-KBS* is constituted of the data, business and presentation layers.

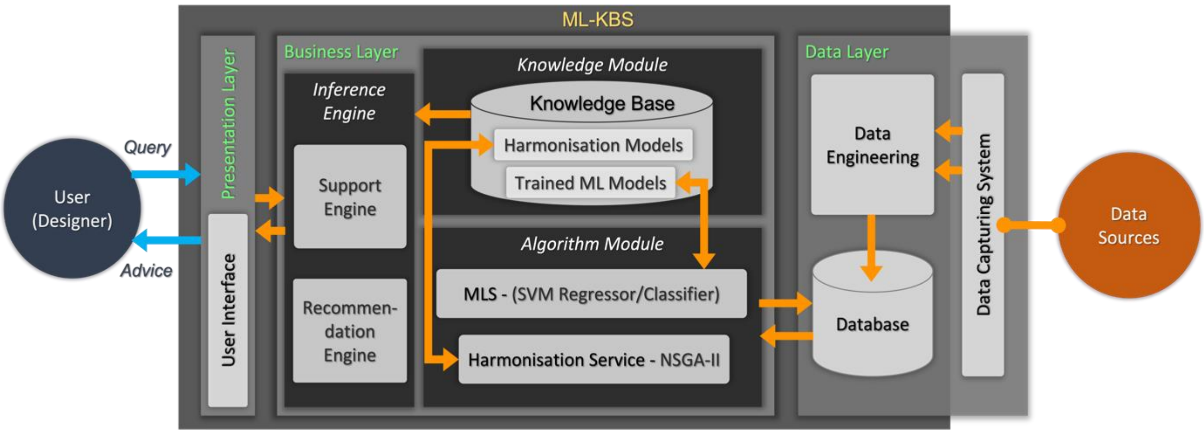

Figure 2. The machine learning knowledge-based architecture of DESMO-APP

The data layer is composed of the *Data Capturing System*, which extracts data from various sources. *DESMO-APP* uses a real physical adjustable motorcycle simulator to capture actual riders' anthropometries, posture and ergonomic discomforts vis-à-vis motorcycle ergonomic measurements. The persona and aesthetic-emotions of motorcycle riders are collected through a survey data collection instrument. This information is composed of the riders' attributes, personality, attitude, and what motorcycles they find the most emotionally appealing. Through the *Data Engineering* and *Database*, the data layer also prepares and warehouses information.

The business layer implements the core functionality of the system and encapsulates the relevant business logic. The *DESMO-APP* business layer is composed of the algorithm, knowledge, and inference engine components. The consequences and support brought forward to the motorcycle designer are based on the interaction between the use-phase motorcycle evolved model and different motorcycle riders with various anthropometries, persona and elicited emotions. By updating the dataset, the rules are automatically updated as new patterns are formed through the training process. With *ML*, complex, inexpressible non-linear rules can be generated from the data. *ML* techniques have the possibility to re-train the model every time new data is inserted, optimising, and refining predictive capacity over time. As such *DESMO-APP* is flexible and capable of producing intelligent responses.

The *Algorithm Module* contains all the algorithms (procedural and mathematical constructs) which are used by the *Knowledge Base* and *Inference Engine* to assist the designer during the decision making. The *Machine Learning Service (MLS)* forms one of the core components of the *DESMO-APP*'s architecture. *ML* techniques generate models, specified as a mathematical relationship between data. As such, the created model is *"a formal representation of knowledge"* (Adèr, 2008). In *DESMO-APP* the main *ML* technique used is the *supervised learning* type *Support Vector Machine (SVM)*. *SVM-*

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Regressor is used to model continuous data type (e.g. handlebar rise dimensions) while the *SVM-Classifier* is employed to model categorical data type (e.g. the severity of an accident and likelihood of occurrence). To attain a harmonised motorcycle design solution, *DESMO-APP* is equipped with another mathematical-based algorithm. The *Non-Dominated Sorting Genetic Algorithm (NSGA-II)* is a *Multiple Objective Optimisation (MOO)* technique, where it solves mathematical optimisation problems involving more than one objective function and where optimal decisions need to be taken in the presence of trade-offs between two or more objectives that may be in conflict. In *DESMO*, the harmonising module balances between four main conflicting objective functions: (i) Minimising total ergonomic discomforts of target user; (ii) Minimising total ergonomic discomforts of general rider; (iii) Maximising total positive elicited aesthetic-emotions of target user; and (iv) Maximising total positive elicited aesthetic-emotions of general rider. For a nontrivial problem, no single solution exists that simultaneously optimises each objective. In *DESMO-APP* a solution is nondominated if none of the objective functions can be improved in value without degrading the other objective values.
In *DESMO-APP*, the *ML* models generated from the *MLS* are then stored in the *Knowledge Base*, which the inference engine can later access. The *ML*-based model is made available and can be accessed by the *IE*, to predict patterns and give advice in case a user (motorcycle designer) makes a query. Also, the *IE* contains other instructions to reason with the computed predictions. After this computation the *IE* will put forward the solution in the form of advice to the user through the user interface.

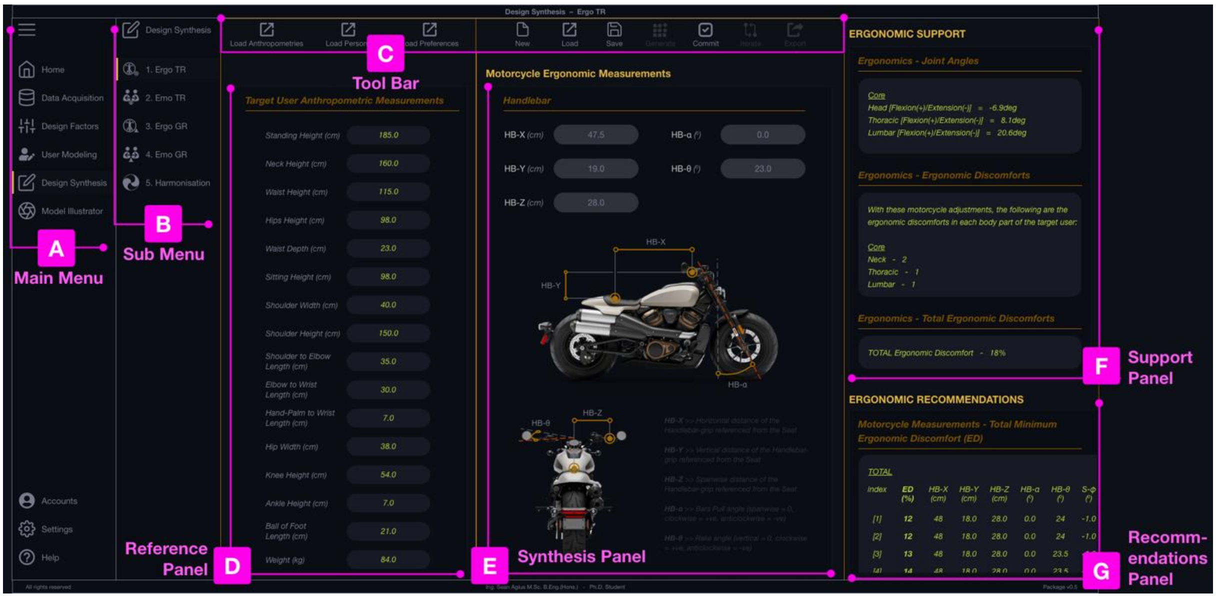

Figure 3. User Interface of the DESMO-APP computational tool

Figure 3 illustrates the user interface for the design synthesis activity. The *Main Menu* (area A) displays the core modules and is the main navigation of *DESMO-APP*. For the design synthesis module, the *Sub Menu* (area B) highlights the sub-modules, in this case, the synthesis stages required for the designer to arrive to a harmonised solution. The *Tool Bar*, area C, is a graphical control element which allows for quick access to functions such as, loading, saving, generating and committing to design decisions. The *Reference Panel* (area D) is an area where the software pre-populates with relevant information. For example, if the designer is setting the ergonomic geometry of a motorcycle for a particular user, the reference panel will be populated by the anthropometric properties of that particular user. In the *Synthesis Panel* (area E) the designer takes motorcycle design decisions. For example, setting a handlebar vertical height or choosing a fuel tank from a list of elements and add it to the evolving motorcycle model. Once the designer commits to those decisions, the *Support Panel* (area F) presents the support in the form of use-phase consequences, while the recommendations for design improvement are presented in the *Recommendations Panel* (area G) by the computational tool.

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3 SOLUTION EVALUATION

3.1 Evaluation aim

An evaluation was carried out in order to establish the validity and effectiveness of the proposed harmonistic framework with respect to the reality situation. Since *DESMO-APP* is a prototype implementation of the *DESMO* framework, the evaluation of the computer-based tool is the indirect appraisal of the framework and its knowledge structure. Prototype tools make it easy for the participants to comprehend the abstractness of the frameworks (Blessing and Chakrabarti, 2009). The objectives set out in *DESMO-APP*'s evaluation are to obtain a:

- degree of evidence that that motorcycle designers benefit from an approach which makes them aware of human factor use-phase consequences and supports them in handling harmonisation.
- critical appraisal on the usefulness, functionality, and usability with respect to the current working practice, and the practical acceptance of the computational design tool.

3.2 Evaluation methodology

The evaluation was based on a case study which provided a demonstration of all the aspects and capabilities of the implemented computational tool and the underlying framework. The case study helped with the demonstration of *DESMO-APP*. This entailed in designing a brand-new motorcycle for a particular user group, with the intent to reach wider riders, and where conflicts between motorcycle ergonomics and aesthetics occurred. A detailed run through each *DESMO-APP*'s modules was carried out by the researchers where ultimately a harmonised motorcycle design solution was achieved. To comprehend better the computational tool, the participants were also given the opportunity to directly use it. Following the demonstration, a semi-structured interview was carried out with participants. A mixed method approach was chosen by the researchers since it provides a structured approach based on pre-planned questions, but still leaves the opportunity for the participant to elaborate on specific aspects of *DESMO-APP*. To quantitatively measure the attitude of the participants, a Likert type 5-point-scale response was utilised. This way characteristics of the approach the designers have found useful and necessary can be assessed. Given that statistical analysis does not always present in depth insight about the participant's feedback and experience, qualitative analysis can fill such gaps when describing the reasons for the supplied feedback. *Inter-rater reliability (IRR)* test was used in this study to assess the replicability and consistency of the qualitative analysis. A *Kappa's index* of 0.74 for the *IRR* was achieved, which suggest a good agreement between the two raters and thus, a good qualitative reliability.

3.3 Evaluation participants

The evaluation was held with 28 international experts in the motorcycle industry with expertise in motorcycles design. The majority of participants came from Europe, with others have worked in the American and Asian markets. The designers' work experience varied between 6 and 40 years (Mean = 18.4. years). During their experience, participants worked with top brands such as Honda, Yamaha, Suzuki, Triumph, Ducati, Harley Davidson and Indian. Most of the participants have a bachelor's degree (82.1%) in mechanical (automotive) engineering (46.4%) and industrial design (35.7%). Participants came from different roles: chief engineers (15.7%); (senior) designers (30%); and design/mechanical engineers (47.9%).

3.4 Evaluation results and discussion

3.4.1 Approach (Theme 1)

As shown in Figure 4 (Q6), all the respondents (N = 28 or 100%) stated that they were guided and supported to find a harmonised solution and have seen it as a very strong feature in *DESMO* (Mean = 4.8 out of 5). *"One of the huge headaches of designers is finding a balance between several aspects. So, the harmonisation and its build up are the greatest features characterising this tool."* Through the use of *DESMO*, the motorcycle designer concurrently designs for multiple human factor aspects at the same time. As illustrated in Figure 4 (Q5), this statement was the second most important (Mean = 4.6) according to the participants, with 71.4% strongly agreeing and 21.4% agreeing. *"The concurrent design for aspects such as ergonomics and aesthetics is important as these usually tend to oppose each other. In reality this is very challenging, but the software simplified it and made it intuitive."* Participants stated (Mean = 4.4) with a total of 85.7% positive reactions, that the tool takes a proactive

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approach (Q8). *"Having a software to help me start and assist me in the early phases is always a good thing. This helps in seeing issues early on and thus, decreasing design change implementation."* Another observation made (Mean = 4.4 and 85.7% positive reaction) was that designers agreed that the approach provides awareness on potential customers' requirements (Q9). *"It helps me to identify the general rider, in order for the motorcycle to be successful in the market."* Although participants had a minor concern since *"a lot of data needs to be collected, but for a concept this should suffice."*

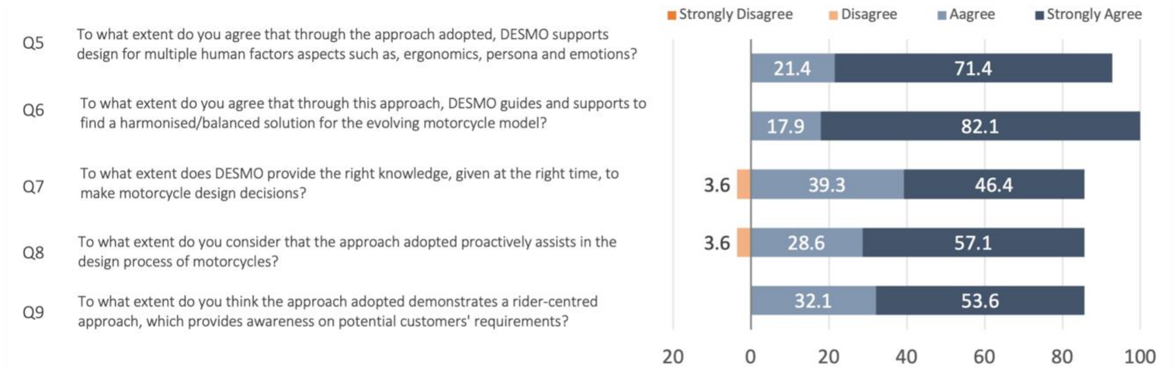

Figure 4. Questions and responses to Theme 1 - Approach

3.4.2 Design Guidance (Theme 2)

The designers collectively agreed (Mean = 4.5, with 60.7% Strongly Agreeing and 28.6% Agreeing) that *DESMO* supports them with the necessary knowledge to avoid or minimise human factors-related ($hf_{E\text{-}AE\text{-}P}$) unintended consequences (Figure 5, Q11). The relatively less positive reactions in this theme are related to questions Q10.a (Mean = 3.9 and 7.1% Negative Reactions) and Q10.b (Mean = 3.6 and 14.3% Negative Reactions). Designers understood that the approach makes them aware of conflicts between ergonomics and aesthetics, as well as between target user and general riders. But they feel this is not projected or highlighted well in the proof-of-concept. *"I could see that there is a conflict occurring between the ergonomics and aesthetics. But it would be nice if this was transmitted visually."*

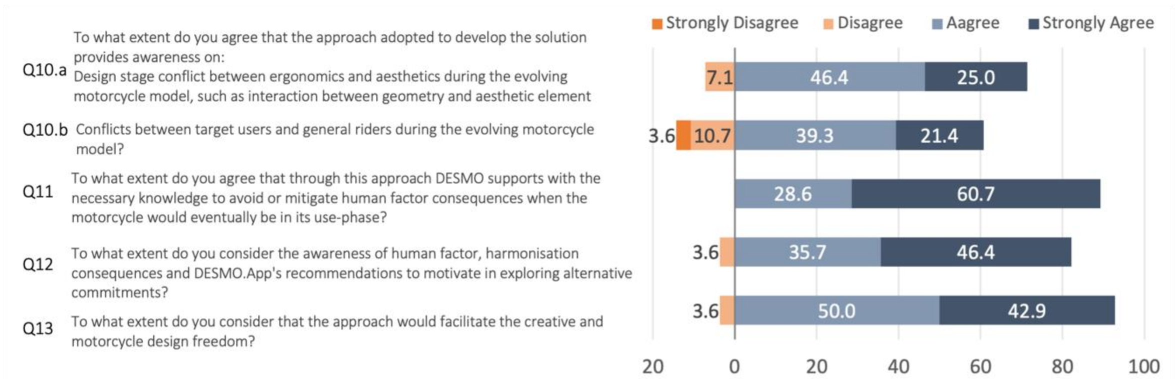

Figure 5. Questions and responses to Theme 2 - Design Guidance

3.4.3 Tool Functionality (Theme 3)

With a mean of 4.3 and 82.1% of positive reactions (Figure 6), participants found *DESMO-APP*, specifically the *"structure, information and UI elements"*, intuitive and easy to use (Q19). The (i) ergonomic properties (Q14.a), (ii) design elements (Q14.b) used to define the motorcycle model, and (iii) user modelling (through anthropometries (Q15.a) and emotion profiles (Q15.c)) in *DESMO-APP*, resemble those properties used in the motorcycle industry. A tool that speaks the language of motorcycle designers is crucial for it to be effective. *"I loved the fact that this tool speaks our language and the way emotions are simulated through mathematical constructs. Stylist cognitively do this without explicitly being aware."* However, participants gave a relatively less positive response to question Q15.b (Mean = 3.5, 17.8% Negative Reactions and 53.6% Positive Reactions), where one participant stated that *"personality is not explicitly included during the design process for mass produced motorcycles."* Although this was a requirement outlined in the problem definition, the industry has yet to fully adopt a shift towards a total user-centred design.

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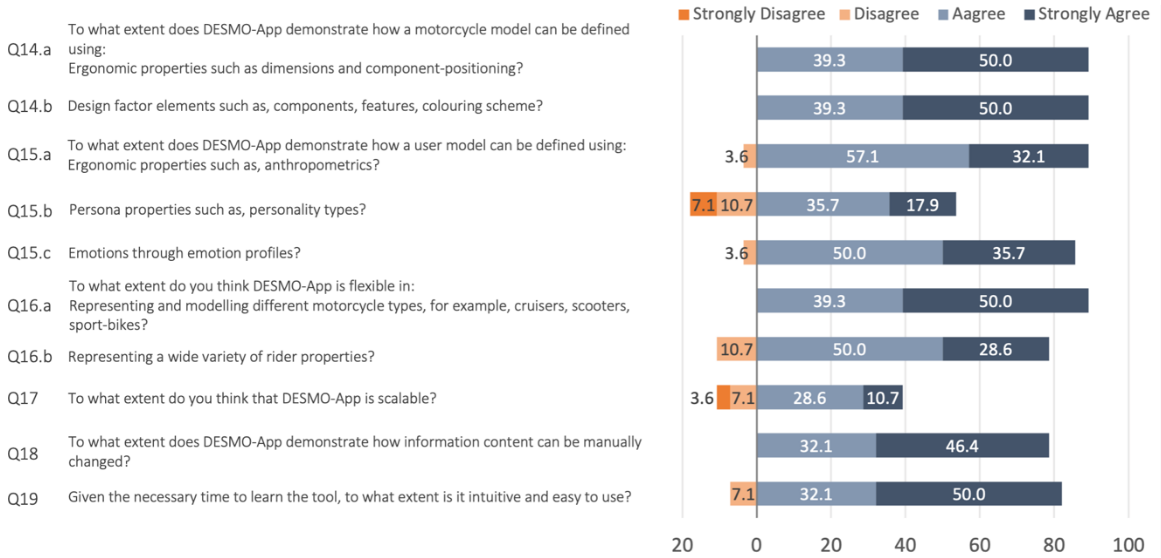

Figure 6. Questions and responses to Theme 3 - Tool Functionality

3.4.4 Relevance in Industry (Theme 4)

With a mean of 4.4 and 92.9% positive reactions, designers stated that they see the relevance of *DESMO-APP* in the motorcycle industry (Figure 7, Q23) and would *"recommend this tool mainly because of its powerful support and harmonisation features as well as because it is compatible with our design workflow."* Participants agreed (Mean = 4.5 and 96.5% Positive Reactions) that this approach would help designers, to design: ergonomically safe and aesthetically pleasing motorcycles (Q21). *"I appreciate the innovation behind DESMO and for sure it will help the company design better motorcycles."* All the surveyed motorcycle designers (N = 28) stated that they have never came across a tool like *DESMO-APP*, which takes into account human factors ($hf_{\text{E-AE-P}}$) and harmonises design solutions (Q22) during their experience in designing motorcycles. This emphasises that *DESMO* is a novel tool which can assist designers. *"I have never seen a similar tool during my 30-year experience in this industry. This can actually fill a gap in the motorcycle design industry."*

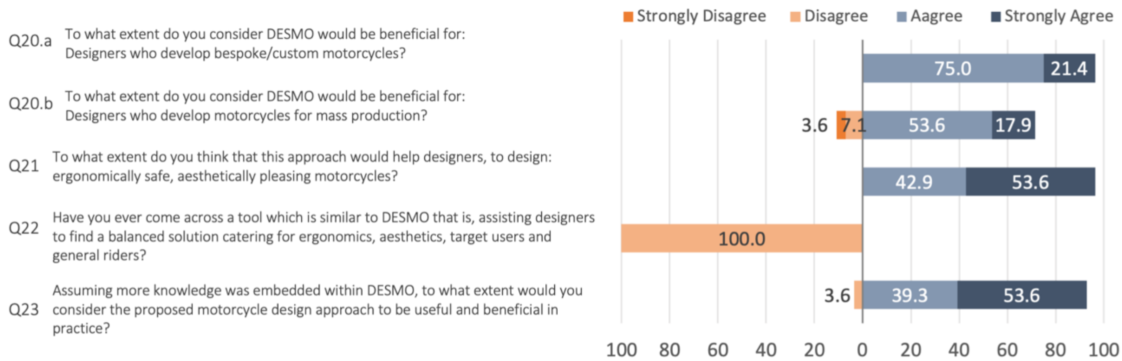

Figure 7. Questions and responses to Theme 4 - Relevance in Industry

4 CONCLUSION AND FUTURE WORK

This paper presented a prototype and evaluation of a smart computational tool which represent the implementation of the *DESMO* framework. As participants have to contribute their own personal time for the evaluation the duration for the demonstration and interview was limited to one hour and a half. Notwithstanding this, the results show that the design support through the harmonistic knowledge-based prescribed approach assisted, guided and motivated motorcycle designers into designing for human factors ($hf_{\text{E-AE-P}}$) at the synthesis design activity. Moreover, validation results showed the necessity and beneficial use of the tool in the motorcycle industry.

The motorcycle artefact was used to exemplify this research. Nonetheless, the computational tool and the design approach framework, extends beyond the motorcycle domain. The developed approach can be utilised to assist in designing medical equipment (e.g. wheelchairs), consumer electronics (e.g.

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smartphones) or sporting equipment (e.g. bikes). Furthermore, the presented approach can be further evolved in future work to explicitly make designers aware of other product life-cycle human factor consequences. For example, making them aware and harmonising conflicts between human factors ($hf_{E\text{-}AE\text{-}P}$) and design for manufacturing aspects.

To address the literature and industry gap, this research contributed a validated novel approach that proactively provides human factors design knowledge and a balanced dual ontological product design solution. This contribution extends also to the machine learning knowledge-based system architecture specifically developed to implement the approach that can be exploited beyond motorcycle design.

ACKNOWLEDGEMENTS

This work was supported by the Malta Council for Science and Technology (MCST), through the FUSION Technology Development Programme (R&I-2017-003-T). Special thanks go to all designers that participated in this study.

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