MODSEAT – Innovative Railway Seat Design

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ABSTRACT

The Modseat project objective was to design an innovative, modular, customisable train seat using new materials and processes. This paper highlights the importance of design methodologies in developing a new seat, from concept design to building physical models to test and validate solutions. We will describe the design process and testing methodologies, presenting the results of the different design iterations. We expect to provide an overview of industry development methodologies and design as a key discipline in articulating different specialists, fostering discussion between stakeholders and creating the best possible passenger experience. The Modseat project was an EU funded project and brought together companies and R&D groups in the Portuguese railway sector to showcase the know-how and technological competence.

KEYWORDS

Railway Seat, Design methodologies, Prototyping, Testing

Introduction

In this paper we will explore the results from the Modseat Project, a regional and inter-city railway seat developed using new materials and processes. The project objective was to meet the future demands of public transportation, through the design and development of a seat to target cost-reduction in retrofitting and disassembly, use innovative materials and manufacturing processes, and provide high standards of designed comfort for the passengers. The design team tackled the challenges of designing a railway seat using a methodology which brought together different specialists and focused on early prototyping to test and validate solutions. The prototypes allowed for several iterations regarding the design, manufacturing processes and comfort testing. We will describe the design process and testing methodologies, presenting the results of the different design iterations. We will also present the final prototype, meant to integrate different percentile populations and provide the functional features for different activities. The experience across different industries has led the design team to develop a collaborative approach to the development of seats, bringing together different companies and using cross-pollination strategies, migrating and integrating technologies and manufacturing processes from other industries.

Methodology

The project methodology included the following steps: Design Concept, Design Development, 1st Prototype, Testing, Design Development revision, 2nd Prototype. The project had a duration of 3 years, with the main steps of the design methodology being developed over a period of 2,5 years. The project included a design consultancy, a manufacturer of metal parts, a materials and process university department, a technical textiles company and a tooling company. The seat was designed and developed according to a railway specification, for an inter-city seat. The methodology followed in the project is described in the following steps:

Design Concept

The initial design target was to increase modularity in the production process, considering a) the assembling of new seats, b) the adaptability of the seat to different market specifications and needs, c) the upgrade of existing units and d) the end-of-life disassembling process. The visual integration of the different parts was developed to reflect a lightweight look and feel, to provide comfort in seating, to enable the use of technologies for the passenger and to test and validate new materials and technologies to produce the seat. Regarding seat comfort, "several studies indicate that increasing leg room, knee space, and personal space have a positive effect on the comfort experience. So, leg room and personal space have a have priority in the design and also expectations and preflight experiences." (Vink, Brauer, 201:25) [1]. The design team used its experience in designing aircraft seats and tried to apply the lessons learned in developing the railway seat, by increasing personal space and leg room, and adding modular accessories like folding armrests and footrests, an "aircraft seat type" reclining backrest and a side-winged headrest for a more comfortable resting position. The seat was also designed with accessories to support the technologies of the passengers such as a folding table (which stays horizontal even when the seatback reclines - Modseat reclining system patent pending) power sockets and USB mobile charging module, as well as a near-field communication (NFC) systems to allow access to infotainment such as movies, music, games, etc. Regarding materials and production technologies, the design team looked for modular and weight reduction strategies, using aluminium alloys and high tensile steels in its structural parts. Processes such as non-welding assembly technologies and cold-forming processes were used to reduce energy consumption in production. The backrest table features a "patent pending" self-levelling fold-down system that allows the table to be kept horizontal at all seat reclining angles. The seat reclines over a backrest bottom pivot, instead of having a "wheelcart" for the seat pan, as railway seats typically have.

Figure 1: Modseat Design Concept

Results of the 3D Virtual Model Verification

Following the Concept Design, the design development phase featured different ergonomic, functional, formal and comfort testing. These tests allowed to make iterations / corrections to the 3D surface models, and after first prototype testing changes were made to accommodate different results from the tested population characteristics and to allow for the passengers to do different activities while seating (such as eating, sleeping or interacting with digital supports). The first design development virtual model followed the railway standard UIC567, which provides standard dimensions to consider in a railway seat, trying to achieve a good comfort compromise. The design team used these basic guidelines and developed a 3D surface model such as depicted in Figure 1. This first iteration allowed the different project stakeholders, namely the different companies and university experts, to discuss the proposals and identify some problems in the future production of the seat. This was the case of the armrest, which, as initially designed, was very difficult to manufacture accounting for the compliance of regulations (more specifically the arm rest load requirements of UIC567), so a second solution was developed with a more robust solution and a simpler folding mechanism, thus improving passenger comfort (by providing and wider armrest) and production. One of the main features of the seat was to have an adjustable backrest. According to UIC 567, in order to increase comfort, the inclination of the backrest should be adjustable in 20º. From the first 3D model, digital “dummies” were used to check for the main dimensions (Figure 2). From the initial verification, the main concerns were regarding the seat pan height, which was too high for both Male and Female Percentile 5, which meant the legs of these users would be without support (Figure 2). Regarding seat width, it was also noted that the backrest width could be slightly larger to accommodate percentile 95 male. The main anthropometric values were retrieved from the Anthropometric Study of the Portuguese Population (Arezes, Barroso, Cordeiro, Costa and Miguel (2006)) (see Table 1). Other features, such as the height of the table and armrests were also revised from the first 3D model and changed before the build of the first prototype.

Population	MP5	FP5	MP50	FP50	MP95	FP95
Shoulder width (bideltoid)	425	394	475	445	525	496
Previous functional range	627	620	730	675	833	730
Seated height	859	807	920	865	981	923
Eye height (ratio seat)	754	703	810	760	866	817
Lumbar Height (seat ratio)	183	187	215	220	247	253
Maximum thigh thickness	146	140	175	165	204	190
Hips width	340	355	380	400	420	445
Knee height	475	435	525	480	575	525
Popliteal height	358	327	400	365	442	403
Poly thigh length	432	421	485	470	538	520
Maximum thigh length	536	518	590	570	644	622
Chest thickness	227	226	265	275	303	324
Abdominal thickness	213	201	265	260	317	319
Seat shoulder distance	575	539	630	595	685	650
Seat elbow distance	206	204	255	250	304	296

Figure 2: Virtual model ergonomic verification with seat structure 15º

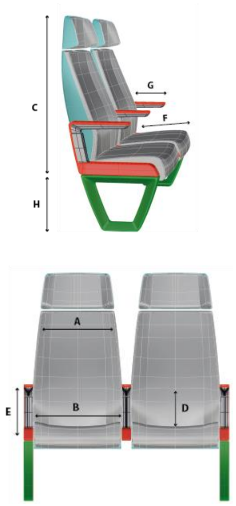

Table 1: Antropomethric measures of Portugues Male and Female Population (Arezes, Barroso, Cordeiro, Costa and Miguel (2006)) Figure 3: Virtual model verification measurements

The first verification was carried out based on the 3D modeling existing to date, and included the following aspects: A - Shoulder seat width should vary between 394 and 525 mm - 394mm, will accommodate people from the lowest percentiles. The P50 is 445 (F) and 475 (M). The suggestion is to increase this dimension, in order to increase comfort and promote an adequate posture. B - Hips seat width should vary between 355 and 420 mm - 408 mm, will accommodate above-average percentiles. If there is a possibility, it can be increased to 420 mm. C - Backrest height should vary between 807 and 981 mm. The measure chosen for the backrest height, 851mm will accommodate people from the 40 percentiles (F) and below P5 (M). D - Height of lumbar support should vary between 187 and 247 mm - 164mm. The measure chosen for the height of the lumbar support, 164, is below the P1 (F and M), 174 and 169. The suggestion is to increase this dimension to accommodate at least the P50 (F and M) 220 and 215. E - Elbow seat distance should vary between 204 and 304 mm - 244 mm. F - Maximum thigh length should vary between 518 and 644 mm - 414mm. Attention to the pressure points of the posterior thigh to accommodate the profiles 10 of the female population and 90 of male population. Attention to the pressure points of the posterior thigh. G - Elbow wrist distance should vary between 292 and 380 mm The measure chosen for the length of the armrest accommodates people from the majority percentiles P1 (F) 280 and P1 (M) 308. If there is interest, it can be increased up to 280 so as not to compromise the handle mobility. H - Popliteal ground distance should vary between 327 and 441 mm to accommodate the profiles 10 of the female population and 90 of male population The measurement chosen for the seat height, 388 mm (including foam) is above the P50 (F) and below P50 (M). The seat coverings, would consist of textile covers, foams and fire barriers, and it was considered that the covers could be made of textile or leather and polyurethane or silicone foams. For typical railway seat cushions, the recommended densities 80 - 90 - 105 (Kg / m3), respectively for headrest, backrest and seat. High density injected polyurethane foams have a low performance compressibility rate. The foam tends to shrink and become loose and the comfort of the seat lowers as more passengers sit on it. The production of silicone foam is a more sensitive and complex process; however, silicone foam does not require fire retardant treatment and does not lose its resilience. As a result, the life of a silicone foam pad is longer and therefore there are also less repair and refurbishment costs.

Results of the 1st (physical) Prototype testing

For physical model verification, a first full-scale prototype was built to enable ergonomic verification, with direct observation of the interaction of users with the seat. Through observation it is possible to understand how prototypes would be used (albeit in a laboratory environment) manipulated, perceived and experienced to create a positive user experience. This model was based on changes made to the first 3D surface modelling. The model was adapted to a simplified prototype, maintaining the essential features for ergonomic verification with regard to the dimensions of the seat pan, seat backrest, pitch between seats, ranges and even functions such as the use of the table and the backrest recline. This model was machined in rigid polyurethane foam and did not have a padded seat pan or backrest. So, a padded foam for the backrest and seat was added to help approximate the density of the seat pan and backrest of the future production version. A physical simplified prototype of the backrest of a second seat was also produced to check available space for the passenger (according to pitch) as well as table height. The prototype backrest had the ability to change degree in order to test backrest inclination comfort. The following images (Figure 4) show the prototype construction and the testing with users.

Figure 4: 1st (physical) Prototype testing

The testing session was carried out by project partners responsible for ergonomic verification, together with an ergonomic researcher who directly observed the interaction with the seat, recording and monitoring the tests with the volunteers. The tests had the participation of 9 subjects, external to the Modseat project, 2 female and 7 male. The height of the subjects varied between 1.54 m and 1.86 m, with an average of 1.70 cm in height. The tests on the prototype built, had the following alignment: Explanation to each volunteer what is intended and signing the authorization; Experimenting the seat in fixed and reclining mode about 5 to 10 min; Completing the questionnaire and suggestions about 5min. Through direct observation of the sample interaction with the seat, some conclusions were drawn about its design, considering the parameters of ergonomic analysis, namely, space for each individual, the space between the seats - pitch, the relationship between the backrest and the seat. Seat with the anthropometry of the different profiles chosen for the sample in fixed and reclining mode and access to the table. From direct observation with the seat in the normal position, it is important to retain the following results: (-) The use of the table was considered difficult for notebooks; (-) Some subjects suggested the need for a lining and padding on the armrest; (this aspect was included in the final version of the seat; (-) Suggestion to improve lumbar support and headrest (cervical area); (-) Suggestion to increase the length of the armrest; (+) There is enough space between the seats to accommodate the lower limbs; (+) Seat height was considered comfortable. From direct observation with the bench in the reclined position, it is important to retain: (-) The use of the table is even more difficult for laptops than in the previous position, it does not allow enough angle for viewing the screen; (-) The lumbar support moves when the backrest is reclined and seems to accommodate only the base; users tend to feel less lumbar support with the seat in this position; (-) The previous situation was also found for cervical support, which was lacking; (-) It was noted that there was a lack of lateral support to support the head to a more comfortable resting position, or even to be able to sleep. Based on the information collected in the virtual and 1st prototype physical tests, it was noted that a lot of changes had to be implemented in the prototype. The main recommendations were collected by the design team and the ergonomic specialist and changes were made to the 3D model in order to accommodate the testing results.

Results of the 2nd (physical) Prototype

After completion of the first prototype and its testing with a group of users, several improvements were made to the design. These led to a second design development iteration and to the development and construction of a second prototype. This prototype would take into account the testing feedback, but also improvements in the production of parts, assembly strategy and parts finishing. Practically all elements of the seat were the object of detailed analysis and redesign. Considering the feedback from the testing, the foam geometry of the seat pan and backrest were redesigned. Also the seat pan height, backrest width and armrest size and height were changed. The backrest table was repositioned, and its dimensions were changed to accommodate the possibility to use a laptop computer. Also, a system was developed to ensure the table would remain horizontal, even with the reclined backrest. Other changes were developed such as the increase of the head lateral supports dimension to improve comfort while resting / sleeping. More lumbar support was provided with more foam padding. The general ergonomics were revised to accommodate both the 5 and 95 percentiles, hence trying to accommodate the whole population. In order to build a final prototype, foam production was done through machining foam with the right density and preparing the model for future production using injection moulded polyurethane foam. The fabric lining covers were produced and the NFC systems were integrated.

Figure 5: 2nd (physical) Prototype

Discussion

The project methodology included the following steps: Design Concept, Design Development, 1st Prototype, Testing, Design Development revision, 2nd Prototype. Actions should follow:

1. Visualize the first Design Concept, fostering discussion between project partners and different stakeholders and allowing to make a first assessment of the proposed solution.
2. Execute the Design Development and first 3D verification (low fidelity prototype) using virtual "dummies" allowed the teams to check the geometric configuration to accommodate different percentiles (namely 5, 50 and 95). This process provided a tool to foster further discussions between partners and was able to provide some information on basic dimensions which were wrong, such as the seat height (which for the percentile 5 was clearly too high). These visual processes of verification can be very powerful as a collaborative tool.
3. Address a medium fidelity prototype - 1st Prototype - at an early stage: only after the first verification process and iteration to the concept design, it was possible to build a first prototype. This prototype was a "medium" fidelity prototype, which used the geometric 3D CAD model information of the seat and backrest, but which did not account for the specific parts of the seat. Nevertheless, it provided an important tool to validate comfort and to make a first physical ergonomic assessment. By also adding the backrest of the front seat, both seat pitch and table height were able to be assessed. It is considered that a way of rapidly prototyping physical models which can be adjusted (such as the backrest inclination in this first prototype) is a very useful tool in the project development to quickly make changes and get user feedback.
4. Use the Design development revision as a fundamental part in refining the 3D model after the first testing. Mainly due to the changing of dimensions and overall proportions, a lot of work went into making all the necessary changes.
5. Achieve a much more refined 2nd prototype that looked closer to the final product with less iterations and investment. It was also built according to the production materials and technologies (e.g., foam, seat covers, metal structure) which would allow for further testing and refinement. Due to the time constraints of the project, no further testing was devised in the second prototype.

Overall, the design methodologies allowed to visualize solutions, were able to create collaborative ways of working and fostering discussions between stakeholders. The methodologies were also able to produce low, medium and high-fidelity prototypes which can enable user testing and validation, balancing the engineering and development effort at each stage. Although the methodology developed interesting results and was able to manage the expectations and include the contributions of different partners, the following recommendations can be addressed, based on the lesson learned from the project:

1. The virtual verification should be done by using the latest 3D virtual "dummies" available, which can work as a "digital twin" of the physical prototypes and help in the concept and development stages. The project used 3D models which are already dates and not the most advanced tools.
2. Low/Medium fidelity prototypes can be used to check for general dimensions, but do not account for the whole look, feel and comfort of a seat. As such, they can be used by researchers and ergonomic specialists to help get dimensions and proportions right. Nevertheless, a high-fidelity prototype must be used and a lot of user testing is needed to validate the design.
3. A laboratory test does not compare to an actual test in a similar setting (train carriage) and timeframe (e.g., 2 hours sitting doing different kinds of activities). Only by testing t in a more real environment and for the duration of a typical train trip, would it be possible to validate the seat comfort. Some authors argue that a possibility is that "discomfort comes into play as a

negative experiencing of a space or whilst using a product" which means user will experience the seat differently, if they are seating in a Lab or cramped in a train carriage full of passengers.
4. Only by using specific measurement tools, such as pressure mats, it is possible to obtain enough unbiased data, capable to being compared to the users feedback and turned into design information to refine the prototypes. Users opinions greatly vary so scientific measurement tools are needed as well as information collection through surveys and questionnaires.
5. The second prototype, already a high-fidelity, was not able to be tested and validated with users.

Conclusions

It is considered that the design methodologies used during the development of the Modseat project prove the role of the design discipline in articulating different stakeholders to develop new products. It also underlines the importance of digital and physical models, and the importance of early prototyping. In fact, we can argue that the more prototypes the better, with increasingly different levels of fidelity to "fail fast" and learn quickly. From study models with low/medium definition for formal and functional validation to medium/high-definition models to refine and validate dimensional and technical specifications, to high-fidelity prototypes to verify ergonomic standards and user evaluation. During the project we were also able to access different opinions about comfort, based on personal qualitative and biased perception. The need to use scientific tools to measure, such as pressure mapping, should be combined with user survey creating a more complete framework to access comfort by combining quantitative and qualitative analysis. Another limitation identified in the methodology was the lab conditions versus real setting for testing and the timeframe considered. For the testing and validation to be closer to a production version of the seat, the tests should be conducted during a typical travel time for intercity trains (e.g., 1-3 hours). This time frame for testing would allow users to experience different activities (such as reading, playing games, resting, etc.). Overall, the methodologies used allowed for a rapid development of a high-fidelity prototype, but due to the complexity of the product, it is suggested that more detailed testing and validation protocols - closer to reality of end use - and experimentation with more rigorous measurement equipment should be considered in the future.

Acknowledgments

The research work reported here was made possible by Almadesign and all partners involved in Modseat Project. The Modseat project aims to reinforce research, technological development and innovation. It is funded by Portugal 2020 under the Competitiveness and Internationalization Operational Program through the European Regional Development Fund.

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