Reorganization and Development of a Car Design Laboratory through QFD and SDE Models to Generate Innovative Projects

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Abstract

This project consists in the set up and preparation of an educational laboratory where the study and implementation of all the techniques and methodologies of Style Design Engineering (SDE) method were fitted. The SDE method, represents a design methodology widely used in the industrial field that proved to add value in the quality of project outcomes. Through numerous previous scientific exercises published and the various projects carried out, the effectiveness of this methodology demonstrated to lead to higher quality project results in the automotive field. It is therefore necessary for the department to have spaces for the exclusive use of this activity, structured in such a way as to be equipped for the training and support of the various students who want to try their skills on car design projects within their final graduation projects. The various phases that make up this activity from a theoretical point of view will then be analyzed and deconstructed to understand which material support they need for their complete realization throughout the process. Implementation of innovative technologies such as AR/VR and 3D printing will be explored to reach the best possible result in the student's works. In this way, during and after the renovation phases, we were able to achieve an overall increase in the quality of student work.

Keywords
Workshop, Design, Quality Function Deployment (QFD), Stylistic Design Engineering (SDE), Car Design

1. Introduction
The importance of this work arises from direct observation of the students' work over the years. The development of car design projects has been one of the key points of interest by the supported organization, by focusing on the study and implementation of the SDE methodology. This model, which is widely used to conduct industrial innovations, is however difficult to study due to the very limited bibliography and literature on the subject. The challenge becomes even more pronounced when some of them want to study the subject even in depth by producing dissertations in this field. The approach taken by the organization to solve this problem, is to provide a permanent laboratory to study, research and testing the different applications of the SDE method. In these premises, students will be able to find the support they need, both in terms of skills, and equipment, to properly develop functional solutions that are validated

as well. The aim would be to study and plan the needs of the future workshop that could be set up in a recently vacant facility, by removing the unnecessary material and build the design workshop according to the study conducted.

In order to plan the preparation of the laboratory, and to gather a detailed list of the essential elements to be set up in it, and to limit resource waste as much as possible, it was decided to adopt the Quality Function Deployment (QFD) method in the whole work. Thanks to the analyses contained in the QFD, it is possible to obtain a very clear idea of the real needs of such a laboratory, proceeding to the various phases of the set-up not through experience and common sense, but through a well-studied and documented scientific method that will allow the optimization of processes and necessary elements in a very precise manner. In fact, the QFD tends to break down the various requirements, arranging them both among themselves, to determine the degree of importance of each, and with pre-established technical characteristics, thus making it possible to extrapolate very precise data on the coupling between the two and obtaining unequivocal answers, which allow you to go to work with very precise ideas on which areas to focus on more, and what instead can be put in the background or even left out. Quality is given a quantitative and measurable dimension, making the process replicable and allowing a project in line with the expectations set at the beginning of the process.

1.1 Objectives

To develop a co-working space in which users' skills are enriched by their diversity of training from various branches of engineering and design, encouraging an important transfer of knowledge.

To set up a design workshop, conceived to specific to the SDE methodology, to study the differentiation requirements from a common design workshop, so as to have the greatest possible working efficiency.

2. Literature Review

User approval of a product is often valuated through separate aspects, office space renovation is an approach that enhances user satisfaction in offices and their functional quality while meeting energy performance goals (Kwon et al., 2019); this approach would led to reach an acceptable tradeoff between health and indoor climate vs functionality and productivity. Nowadays, office spaces that are engineered to green standards led to achieve better productivity (Liang et al., 2014); assessing the impact of acoustic quality (Kaarlela-Tuomaala et al., 2009), lighting (Nicol et al., 2006), temperature (Kosonen & Tan, 2004) and air quality (Mahbob et al., 2013). However, researchers also found that an office space has to offer infrastructure adaptability so the area could be fitted to more than one specific purpose (Arge, 2005). Nevertheless, learning efficiency is strictly linked to a proper infrastructure (Barrett et al., 2019), which depends in both physical space and comprehensible equipment inclusion ought to improve education accuracy (Zineldin et al., 2011).

Moreover, the SDE methodology, also known as the "Pininfarina method" is a design technique that has long been successfully used in the industrial field, and in the field of car design (Giampiero Donnici et al., 2020). It consists of the systematic arrangement of tasks gradually led by the design team, labor of which has turned very rigorous and objective compliant, to obtain a model with the best possible characteristics and in full correspondence with the project targets set at the beginning of the work. This begins with the analysis of the style, a very accurate and precise study on the history of the style of the company under consideration (Leonardo Frizziero, Donnici, et al., 2021). Then follows the sketching phase, essential for putting the first ideas on paper and which are gradually being perfected until satisfactory shapes and sketches are reached. Afterwards, a 2D table of the best and most appropriate sketches is performed for comparison, in order to better evaluate the proportions of the whole and of the individual parts. However, the most complex part is the creation of the 3d model based on the 2d tables selected, so a proper prototype could be created afterwards with additive manufacturing technologies or even Augmented Reality (Santi et al., 2021), as prototyping allows to evaluate the lines and proportions of the model live and in a tangible way (Piancastelli & Frizziero, 2014).

3. Methods

A sustainable design must consider a wide array of characteristics, due to guarantee adaptability and optimize social, economic, and ecological impact (L Frizziero et al., 2018). Through this procedure, the main elements and the most important characteristics to focus on are identified. From this process it is possible to derive the best elements from past challenges and carry over such in future challenges (Piancastelli et al., 2014). Decisions for each element derived from a specific need expressed by the implementation of the SDE method (Leonardo Frizziero, Santi, et al., 2021). This step was carried out mainly to get a general idea of the aspects to focus mainly and thus be able to have a first overview of the problems and needs so the best subsequent methods to adopt would be decided (G. Donnici et al., 2019).

SDE is a widely used industrial methodology for innovation in car design. This method consists of various steps to be carried out in sequence; the correct success of these can lead to projects consistent with both current market trends and with the history of the brand for which the design is performed.

The work begins with one of the most important phases of the entire process, the study of stylistic trends (Frizziero et al., 2021), as key decisions taken at this point that would rule out the entire successive steps. A large part of the serious mistakes that can be made during the subsequent design phases are often due to a bad or insufficient study in the initial phase of the project. The study takes place taking into consideration the parent company of the car model that is going to be designed (in the case of car design) and we begin to study the history, the key moments of its path, positive and negative, and in general all the stages that have brought it to the present day. Then we go to analyze all his stylistic past, identifying here too some salient moments that act as a guiding thread in his evolution.

After the study, we move on to the phase of sketching on paper. Thanks to the knowledge and forms acquired in the previous phase, it is now easy to imagine and trace forms as consistent as possible with the reference company and its style. In this way the style and the personal trait of the designer are preserved and emphasized, but still remain within solid guidelines that help him during the process to draw sketches that are not only beautiful for his taste, but significant for the project that is carrying on. Different sketches are then made for each of the different stylistic proposals until a rather complete and heterogeneous picture of the situation is obtained. After a selection, the last remaining sketch is modified and refined until a stylistically consistent and satisfactory level is reached.

After having selected the sketch of greatest interest, it is time to transform it into a rigorous 2d computer drawing. This is a very important step because in freehand sketches the shapes often tend to be very "emotional" and obviously out of proportion. This drawing technique, useful in the initial definition phase of the sketch, proves to be inefficient when evaluating the real beauty and proportion of the product, since many elements are exaggerated with the result of making even a drawing of a product look beautiful. Therefore, the 2d table setting helps, which, being very rigorous, suddenly makes the lines much more realistic and allows us to judge the model for what it is likely to be. In this way, any weaknesses and disproportionate elements are understood very well, being able to have a clear overview. The appropriate changes are then made in the areas where the need arises, and the 2d drawing is updated.

At this point the 2d CAD tables are inserted into a modeling software where they become a three-dimensional model of the project, as it was intended in the previous steps. Exactly as happens when the sketches are transformed into 2d tables, also in this step the rendering of the shapes of the model will not completely coincide with the 2d lines. Once the model is finished, therefore, its proportions are evaluated from every possible point of view, and the stylistic weaknesses are immediately visible at this point. Also in this case, therefore, the model undergoes various transformations, both to restore the correct proportions and to make evident the style concepts born in the sketching phase, which are often lost in the rigorous phases of subsequent drafting. In this phase, the model is also detailed, with the shapes that are gradually refined, such as in the case of an automotive project, the style lines on the bodywork or the details of the bumpers.

Thanks to 3d modeling it has been possible to have a realistic and plausible form of how the project will come in a digital environment. However, the monitor display has limitations, such as the correct display and definition of the curvature of the surfaces, and the always very difficult management of proportions, which in a product such as a car must be organic and harmonious from any view direction. To achieve this, a physical model of the project must necessarily be created, first to scale, then to life. In this way it is possible to obtain, with extremely reduced costs compared to the past, models that are exactly faithful to the shapes of the CAD files. Once you have the model in your hand, you can make sure of the goodness or otherwise of the shapes drawn and make changes and corrections to the files until you reach the desired shape. With the final forms, therefore, it is possible to create a full-scale model in clay and to evaluate the true forms and proportions. Moreover, thanks to the workability of the material, changes can be made directly to the model, even with complex geometries, and immediately assess their effectiveness. These changes can then be scanned and imported directly into the 3d file, greatly speeding up the workflow and its effectiveness. At the end of all this procedure, it is therefore certain to have created a model with coherent shapes and proportions and exactly in line with what had been imagined.

At the end of the previous phase, the result is a file representing the finished project from a stylistic point of view. At this point comes the important phase of communication, that is to convey the coherence, organicity and beauty of the lines drawn even to those who have not taken part in the project, and therefore, implicitly explain the reason for those precise stylistic choices. It is also the phase of color choices with the various respective combinations and scenarios of use of the product in question. In order to do this, digital renders are used. Thanks to the renderings it is in fact possible, through the assignment of materials to the various components of the product, to make the three-dimensional models realistic, exactly as they will be after they are put into production, thus making their shapes clear even to the layman, and allowing to virtually recreate scenarios. and places of daily use of the product. In this way we can create images for product presentations, but also advertisements, both photographic and video.

Subsequently a research approach is adopted, in which the ways in which others have already solved similar problems are studied, going to deepen the study regarding the realization of stimulating design workshops for engineers and designers, which go to stimulate creativity and integrate and train new skills in project work situations deemed similar. In this way it was possible to identify the solutions that bring the greatest advantages not only in the setting up of the structures themselves, but also in the subsequent operational phases within the future projects of students and undergraduates. Making a selection of existing laboratories has made it possible to extrapolate from a conceptual point of view the essence that these tools must transmit to their users, allowing to have an even more precise framework within which to move and starting to identify bankruptcy solutions that can already be these phases be discarded or even evaluated in a different perspective.

Areas Definition

This project takes place within three rooms of the Montecuccolino experimental facility. The structure of these three rooms will be designed to complement each other in functionality. The first room, seen on Figure 1-1, is light and airy, thanks to the full-length glass wall and a large table already on existence, it therefore lends itself to various applications and could be the main office of the structure in which the study and design activities are carried out. To the side, there is a slightly smaller room Figure 1-2, square in shape and with a few tables present: this could be the room in which to position some useful machinery for making prototypes and studying rapid prototyping technologies. Finally, the third and last room on Figure 1-3, the largest of the three, rectangular in shape, with a wide granite shelf along one short side, of a height suitable for working while standing. This room is in the center of the building and has no windows, which could make it suitable for photographic use, making it easier to control light, and similarly could be important for facilitating the implementation of AR/VR technologies within projects.

However, the QFD methodology will be adopted in order to gather the necessary aspects to improve the learning experience. Quality Function Deployment (QFD) is recognized worldwide as one of the most powerful decision support tools in product and service innovation contexts. The QFD uses calculation matrices, interviews and brainstorming sessions to improve understanding of Customer Requests, correlating them with the concept of new product development process (Chan & Wu, 2002). QFD is also a method for focusing the entire business organization in an orderly manner towards the product features that are most important to the customer.

1

2

3

Figure 1. The three rooms available in the Montecuccolino structure. The office room (1) the machinery room (2) and the photography room (3)

We could summarize the definition of Quality Function Deployment according to these points:

- The QFD aims at excellence in the quality of a product or service, in the broadest sense of the term, evaluated in terms of customer satisfaction
- The QFD uses mathematical methods that are objective or at least as objective as possible (the component of subjectivity is still present in the evaluations of the work team)
- The QFD unfolds along the entire product development process, from market analysis, to design, to industrialization, to pre-production (the method can in any case and normally undergo variations or interruptions without compromising the results up to that point reached)
- The QFD tries to correlate also and above all non-homogeneous contexts, for example customer needs and product characteristics, defined in the design phase
- The QFD tries to involve all company functions at the organizational level
- The QFD ultimately helps managers or members of a work team to make operational decisions and make the necessary compromises by providing a complete, clear and robust methodological path.

In carrying out this project, three methods of QFD analysis were used: the Six Quest, the Relative Importance matrices and the What - How matrices. Let's go below to analyze them individually. The first method used is the Six Quest or 6 Questions method: it consists in creating adequate answers to the six fixed questions that are asked. The questions respectively are: WHO, WHAT, WHERE, WHEN, WHY, HOW. The method consists in formulating very concise answers to each of these questions, generating a small description of the area of use in which a proposed product will be used, based on the question asked. This system allows you to easily identify problems by breaking them down into smaller and easily solved parts. In addition to the answer, you can enter one or more keywords that further summarize the content, and already give clearer information on the project direction to be undertaken. Subsequently, the Relative Importance Matrix method was applied. The goal of the method is to try to understand which of the characteristics of the product are more important, and which ones are instead in subordinate positions.

The first step is to choose adjectives or characteristics that fall within the potential sphere of interest and use of the future product. These words are inspired by what we have seen as answers from the Six Quest method; the words could even be the same summary keywords. A rectangular table is then created, and these keywords are arranged along two lines, one at the top, the other along the left side. The words are arranged in the same order, starting from the top left corner of the table. At this point the analysis begins. Proceed horizontally, you will evaluate the words on the column with those on the top row. A score will be assigned in the table boxes: 2 when the characteristic expressed by the word in the left column is more important than the one on the top row, 0 when it is less important, and 1 in case of a tie, or simply when the word meets. with itself. We proceed in the same way for all the characteristics we have set for the product, until we have a numerical column on the right, with values deriving from the horizontal sum of the individual evaluations. Let's go immediately to highlight the highest and lowest values, or we can simply rank them in descending order: in this way we have a schematic and analytical answer to our question about which characteristic among those choices is essential and must necessarily be part of the project, and what are the elements that can, if necessary, be neglected or investigated in a minor way, given their minor importance.

Structured in a similar way to the Relative Importance Matrix, the What - How matrix also develops along a rectangular table. The goal of this analysis is to understand what are the elements that make it possible to realize the characteristics of the previous table, hence the name thing - how, that is: which elements of the How have the greatest impact in the realization of the Thing. The same words of the previous matrix are placed on the left column, in order and starting from the top left corner; represent the What. In the top line, instead, words enabling the realization of the various things, or the simple characteristics of the product, or ideas and design choices are put. This time the evaluation will be done vertically: we should understand how much the characteristics above are influential for the words in columns on the left. Being a more complex evaluation, the numerical evaluations will be more articulated: 9 points for maximum influence, 3 for good influence, 1 for poor, and 0 for no influence. As before, the points will be added up, this time however vertically, and a numerical line will be created on the bottom. The characteristics that have obtained a higher evaluation will be the most important ones for the product overall, and vice versa. Furthermore, for a more truthful overall reading and which considers the complexity of the project in its entirety, this result can be combined with the result of the previous table. In fact, if from this analysis a very high value will come out in response to a characteristic deemed uninteresting in the Relative Importance Matrix, it will certainly have a lower value than a good result linked to a characteristic previously considered very important.

As explained in the previous paragraph, most of the most significant results derive from the application of the QFD method, deployed in Figure 2. These results are in fact much more detailed and precise than those extrapolated from the preliminary stages of study and research and are therefore of decisive help for an optimal success of the design process (G. Donnici et al., 2021).

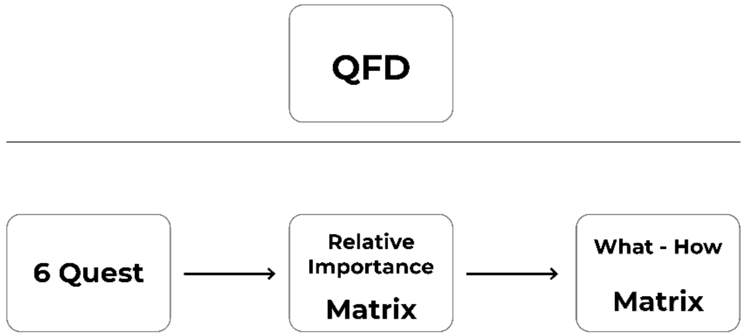

Figure 2. QFD methodology deployment

From the first two steps of the analysis, we understood the importance of many key concepts that can in fact be found in many design laboratories around the world. However, this laboratory is different since it focuses almost exclusively on the development of projects concerning the SDE methodology, consequently its purpose of use will certainly have to be more targeted than a laboratory with a more generic vocation and will certainly need some specificities within of the widest panorama of design workshops. These very important characteristics are especially during the various steps of the QFD analysis. In particular, the main forms of study provided by the analysis were 3: the analysis of the 6 Quests, the Relative Importance Matrix, and the What - How Matrix. These analyzes were carried out in sequence starting from the 6 Quest analysis. In this way, they have made it possible to uniquely define the indispensable needs of a structure of this type, finding, through targeted questions, the key concepts that must necessarily be considered in the phases of project planning that are being carried out.

4. Data Collection

Thanks to the concepts extrapolated from the previous analyzes, it was therefore possible to carry out the following ones: based on what was previously defined, it is now possible to derive the key characteristics that can be inserted within the Relative Importance Matrix (Donnici et al., 2021). This specific analysis compares these newly extrapolated characteristics with themselves, thus defining a hierarchy of importance between them and allowing, if necessary, to discard the elements deemed less useful, not on the subjective basis of personal considerations, but thanks to suggestions of these objective analyzes that allow a measurement in qualitative terms of peculiarities that otherwise would lend themselves to a more subjective and therefore potentially erroneous judgment. These considerations can therefore lead at this point to the third analysis of the QFD methodology: the What - How Matrix. Thanks to this analytical procedure, we can systematize the characteristics previously studied with the various steps of the SDE methodology; in this way we have a clear and objective view that allows us to extrapolate data of great use. In fact, in this way it is possible to understand very well which of the previously studied characteristics best lends itself to being associated with the various steps of the SDE method.

5. Results and Discussion

In this section we examine the results of the QFD analysis, which indicate the precise way forward for the most effective achievement of the project objectives. The QFD components used within the planning of this project are the 3 described above, the 6 Questions, the Relative Importance Matrix and the What - How Matrix. These analyses should be carried out sequentially as the results of one will affect the structure of the next. The data as extrapolated from the various analyses using the QFD method is shown and remarked on Figure 3.

Six Questions:
WHO - who uses the lab?

WHAT - what is it for?

WHERE - where can you work?

WHEN - when is it used?

WHY - why is it used?

HOW - how is it used?

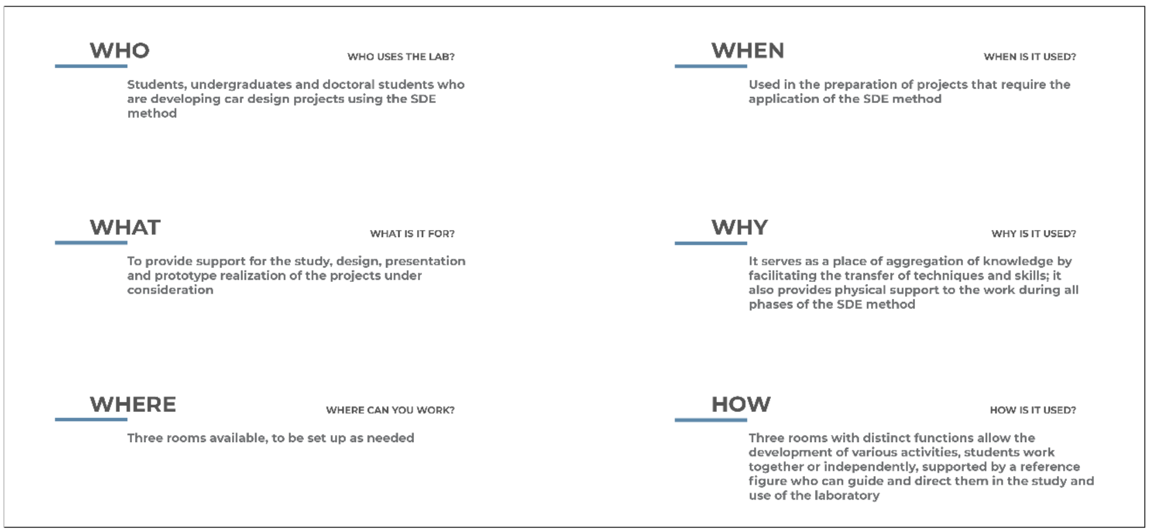

Figure 3. Six Questions

From this analysis we extrapolate the basic characteristics to be implemented in the laboratory. Summarizing the findings, we form the categories for the next analysis, the Relative Importance Matrix. These characteristics are empty tables, habitability of spaces, usage versatility, computer at disposal, equipped walls, trained staff, prototyping machines, AR/VR equipment, mechanical workshop.

5.1 Numerical Results

From the relative importance matrix, seen on Table 1, it was possible to extrapolate the characteristics of greatest importance with reference to those previously selected (Frizziero et al., 2018). In the first places we have therefore the possibility of having rapid prototyping equipment, the presence of a workshop for manual work, the presence of adequately trained support staff, the availability of large, clear tables to carry out the first stages of research and study and deepen the sketching, and the presence of equipped walls on which to hang both the best sketches from which to take inspiration, and those of the students in progress to have an immediate visual comparison of the evolution of the work; 3D printed models can also be exhibited, so that the consistency of the proportions of certain reference models can be seen at first hand. Some characteristics were considered of secondary importance, such as the availability of a computer workstation, since the work can be carried out on the students' laptops, given the absence of particularly specific software, the versatility of use, given the highly specific nature of the workshop to be set up, and the size of the spaces, justified by the fact that most of the work can be carried out in fixed workstations.

Table 1. Relative Importance Matrix:

(the green square next to the name shows the winner of the analysis as a result of the number in the TOTAL column on the right)

	EMPTY TABLES	HABITABILITY OF SPACES	USAGE VERSATILITY	COMPUTER AT DISPOSAL	EQUIPPED WALLS	TRAINED STAFF	PROTOTYPING MACHINES	AR/VR EQUIPMENT	MECHANICAL WORKSHOP	TOTAL	
□ EMPTY TABLES	1	2	2	2	1	1	1	1	0	11	□
HABITABILITY OF SPACES	0	1	1	2	0	1	0	0	1	6	
USAGE VERSATILITY	0	1	1	1	0	0	0	1	0	4	
COMPUTER AT DISPOSAL	0	0	1	1	0	0	0	1	0	3	
□ EQUIPPED WALLS	1	2	2	2	1	1	0	1	1	11	□
□ TRAINED STAFF	1	1	2	2	1	1	1	1	1	11	□
□ PROTOTYPING MACHINES	1	2	2	2	2	1	1	1	1	13	□
AR/VR EQUIPMENT	1	2	1	1	1	1	1	1	1	10	
□ MECHANICAL WORKSHOP	2	1	2	2	1	1	1	1	1	12	□

In this table we can see the winner categories of the analysis: these are empty tables, equipped walls, trained staff, prototyping machines, and mechanical workshop. It is now important to determine the importance of these categories in direct comparison with the various steps of the SDE method. In fact, these steps cannot be modified because they are part of the design methodology; the categories analyzed, however, can still be changed to better suit the design process.

Table 2. What - How Matrix:

(the green square next to the name shows the winner of the analysis as a result of the number in the TOTAL column on the bottom, the second row of squares shows the winner of the previous analysis, the solid green square shows the winner by detachment of a given category)

	EMPTY TABLES	HABITABILITY OF SPACES	USAGE VERSATILITY	COMPUTER AT DISPOSAL	EQUIPPED WALLS	TRAINED STAFF	PROTOTYPING MACHINES	AR/VR EQUIPMENT	MECHANICAL WORKSHOP
ACTIVITY PLANNING	3	1	1	1	1	9	0	0	0
DESIGN RESEARCH	3	1	1	1	3	3	0	0	0
SKETCH STUDY	9	3	0	1	9	9	0	0	0
SKETCHES REALIZATION	9	1	1	3	9	3	0	0	0
2D DRAW	1	0	0	1	1	1	0	0	0
3D MODELING	1	0	0	3	0	3	1	3	0
RENDERING	0	0	1	3	3	3	0	9	0
AR/VR IMPLEMENTING	0	0	1	3	0	3	1	9	0
PROTOTYPING	3	3	3	1	3	3	9	9	9
TOTAL	29	9	8	17	29	37	11	30	9
	□				□	■		□	
	□				□	□	□		□

As it could be seen, from the Six Question analysis it was possible to extrapolate the key concepts to begin to form a precise idea of the various steps to be followed for the subsequent steps. Subsequent analyses were used to further narrow the field and validate the results obtained. Moreover, the Relative Importance Matrix allowed to understand which of those characteristics were most influential and of greatest importance in order to support the projects in progress (Baldrati et al., 2021).

With the What – How Matrix, seen on Table 2, on the other hand, it was possible to systematize the results obtained with the previous analysis with the various consequential steps of the SDE methodology, to understand which of the characteristics found had the greatest influence, at the same time validating and integrating the results of the previous analysis.

Necessary Equipment

From the matrix in Table 1, the winning elements were: empty tables, equipped walls, trained staff, prototyping machines, and mechanical workshop. Other elements, such as computers at disposal were found to be of secondary importance and therefore in these early stages of restructuring can be put aside going to shorten the construction time, without this being a detriment to the function of the laboratory.

The What-How matrix provided further confirmation of both the winning and losing features in Table 1. Empty tables, equipped walls and trained staff were confirmed. On the other hand, prototyping machines and mechanical workshops received a lower score, making them important, but less so than what emerged from the first analysis, due to their intervention in the SDE cycle only in some sectoral phases. However, there remain crucial elements that certainly cannot be overlooked. In addition, the importance of AR/VR equipment emerges, which was not a winner in the Relative Importance Matrix.

Table 3. Necessary Equipment

				TOTAL
TRAINED STAFF	11	+	37	48
EMPTY TABLES	11	+	29	40
EQUIPPED WALLS	11	+	29	40
AR/VR EQUIPMENT	10	+	30	40
PROTOTYPING MACHINES	13	+	11	24
MECHANICAL WORKSHOP	12	+	9	21

In Table 3 at this point, the key features on which to pay priority attention in the design phases are highlighted, these features have also been arranged in increasing rankings to further highlight the degree of priority among them. In first place is the presence of trained staff, followed by empty tables, equipped walls, and AR/VR equipment in equal measure.

Discussion

On the basis of the analyses carried out, it was possible to set out a precise design direction and start work. Since there was an urgent need to continue with normal university activities, the work graduate students in the field of car design certainly did not stop, so the renovation work was carried out in parallel. The work therefore started gradually, with the aim of slowing down activities as little as possible.

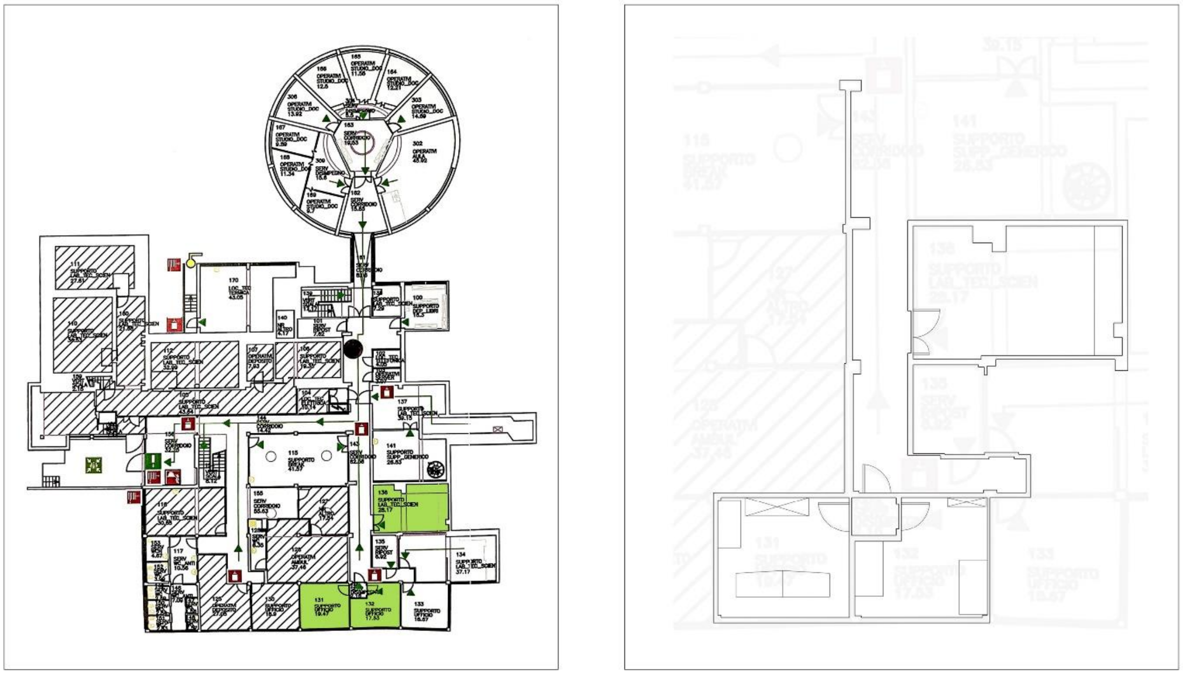

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Figure 4. The three rooms available in the Montecuccolino structure, colored in green (1) and the planimetry of the rooms (2).

The first thing to do was to relocate the students' working and reception areas. The students were the first to arrive at the laboratory in Montecuccolino and were immediately involved in the project. Previously they did not have a place where they could work independently and be received for revision by professors and graduate students, so they had to go, when summoned, to the Department of Industrial Engineering, in the main office of the Faculty of Engineering, being able, however, to stay for a few minutes, compatibly with the space and time requirements of a place not created for this function, populated by many professors and staff in the performance of their activities. Already from this moment it was possible to observe an acceleration in the students' work schedules, especially as regards the first phases: those of general planning, in which being able to have a full-time coworking space dedicated to this specific type of work represented a great advantage.

At the same time, graduate student was selected to work specifically in the automotive field and to deal on a daily basis with the development of works using the SDE methodology, and to set up his operational headquarters not in the Department, like all the other graduate students, but in the Montecuccolino laboratory itself, in order to guarantee maximum presence and working effectiveness, both for his individual research work and in supporting the students. In this way, a further boost has been given to the students' timeframes and abilities. In addition to the location, they can now be assisted at any time and in the continuity of their work by specialized personnel who can follow and organize all the various stages of their work. In fact, in addition to support in the initial stages of study and work, it is also possible to provide support for design, also going to carry out specific teaching where the need arises, in the various stages, such as sketching, a subject many students have never studied, or the introduction and support in the use of specific software for creating virtual 3D models and renderings. The next step was to see and catalogue all the objects already present in the premises: a large part was cleared out, restoring the original habitability of the rooms, while products judged to be of good use were recovered and, if necessary, adjusted and put to new use in the future workshop.

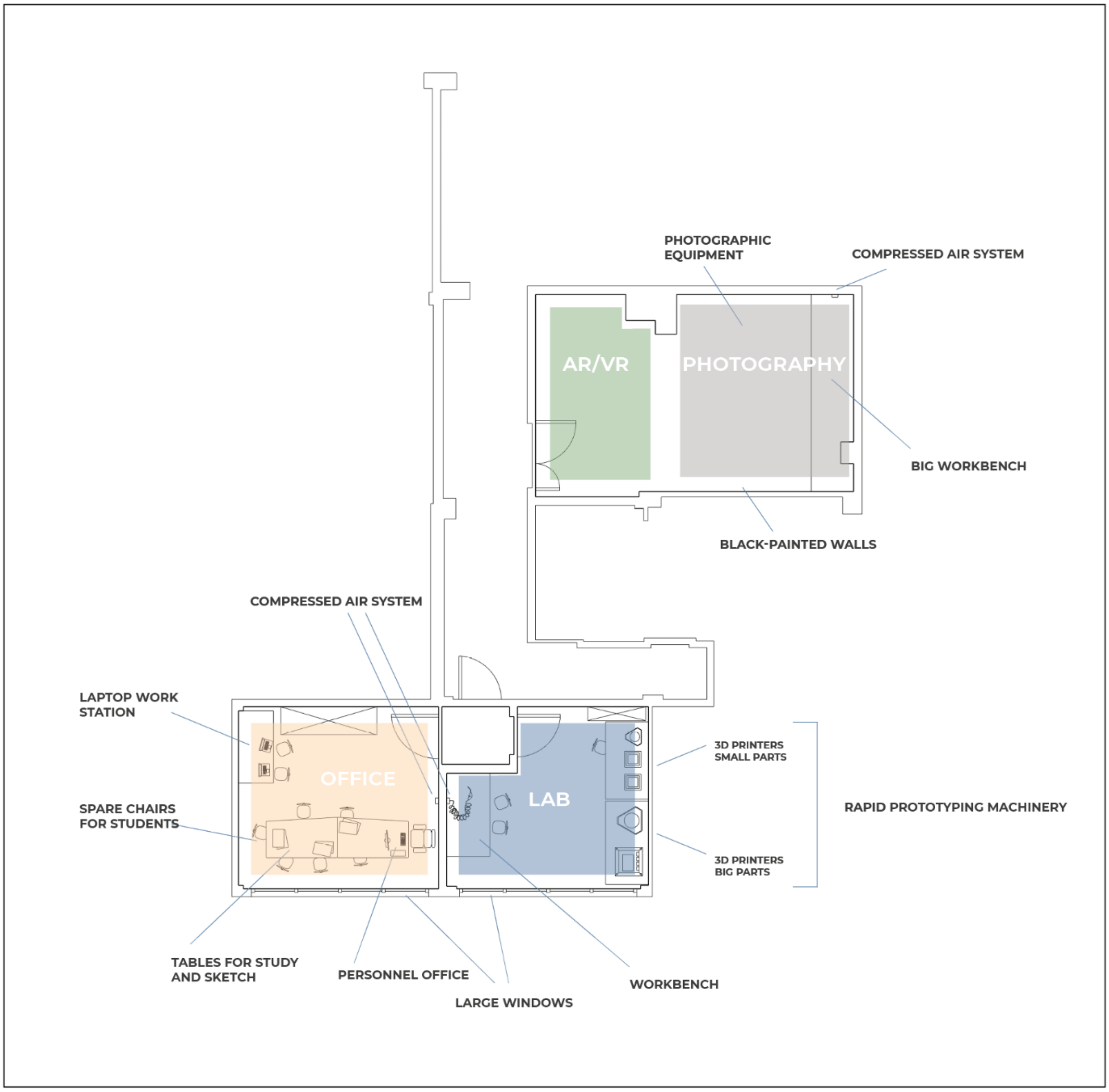

Figure 5. The new setup of the space available as a result of the analysis carried out

One of the points judged most important by the QFD analysis was the availability of a mechanical workshop for manual work. This type of service can be of great use in the final phase of projects, during the prototyping phases, as emerged from the What - How matrix. The facility, being a former nuclear research laboratory, has large spaces and several rooms: in one of them there is a workshop equipped with many tools and machines, and a specialized technician who is able to make mechanical parts from the CAD design, which he has made himself. This structure can therefore be fully used to support the students' work and was therefore integrated with elements that could further support the automotive field.

A further step was then taken to plan the installation of machinery for rapid prototyping and the production of parts, components and style models. Two FDM technology printers were positioned, one of which was large, and one capable of printing 5 different materials in the same model. Boxes have also been set up for dehumidifying and maintaining the coils. In this regard, the Department has PhD students with high expertise in the field, who carry out innovative experimentation in the field of 3D printing, from whom we can freely receive support. The Department is also involved in innovative experimentation in carbon fiber lamination, and such equipment has been brought into the Montecuccolino laboratory for greater integration and exchange of expertise between similar fields. An additional worktable has also been mounted in the printer room to provide more space, and it is planned to mount three more small 3D printers to lighten the workflow of the main ones and quickly produce small components; for greater efficiency, these printers will not be purchased new, but will be recovered and adjusted from models in other spaces that have fallen into disuse due to technical problems.

5.3 Proposed Improvements

The results are thus fully satisfactory and in line with what was hoped for at the beginning of this project path, but as happens in all innovation projects, points and further improvement strategies can be found. One of the next objectives concerns the implementation of AR / VR technologies within the students' design paths. Currently, in fact, augmented reality or virtual reality technologies are mainly used at the end of the project, once the product has already been completed, as a further final visual validation of shapes, sizes, proportions and reflections. The next step concerns the inclusion of these technologies also within the intermediate steps of study and construction of the projects themselves, in such a way as to make the already many advantages present even more important. In this way it will in fact be possible to obtain realistic visual confirmations relating to the various progress steps, potentially guaranteeing a significant shortening of timing and an increase in quality. A further possibility could be given if the quality of the implementation of these technologies were convincingly high, i.e., the partial replacement of physical models, made through 3D printing processes or manual manufacturing of the models, in order to have more realistic images, less use of materials and physical machinery and, here too, further decreases in the time required.

5.4 Validation

Upstream of all the analyzes shown here, a direct validation of the goodness of the work is given, as previously referred to, thanks to the continuous work of the students during the entire planning and improvement period of the laboratory. In the first place, the direct feedback received from the students themselves was of great importance, who during their processing phases were able to witness the progressive change of the structure and functionality from the inside. In fact, the students were involved from the very beginning, providing them with a place to work on their projects. Even with the bare rooms, they immediately benefited from the situation, thanks to the immediate support with a graduate student who helped them to set up the first phases of work and to proceed with the next steps. Progressively the environment changed, and it was therefore possible to immediately notice the changes that the structure was able to bring to the projects of the children, to the ease they found in individual work, and to the quality of the ideas that came out, significantly increased thanks to the exchange of advice. and opinions between them. The mutation of the environment met them in this sense, providing them with spaces with large tables where they could carry out brainstorming or sketching sessions, learn skills they did not possess or deepen new ones according to the requests of the individual jobs. The comparison also continued in the subsequent phases of the SDE methodology, such as the 2D drafting work and the various phases of 3D modeling and Render.

6. Conclusion

In order to uniquely verify the achievement of the project objectives set out at the beginning of the paper, during all the phases of the re-design of the laboratory, The stage of progress of these projects was very heterogeneous, with children in the final phase and students at the absolute beginnings of their activity (Francia et al., 2018). All these projects had as a common denominator the presence of the SDE methodology as a driving force of the various processing phases, although presenting different themes, therefore, they were united by some conceptual aspects and therefore all of great use for this study. The very fact of being in various stages of development made it possible to evaluate the interface between the stages of processing in progress and the growing structure of the laboratory itself that was taking shape over time. Thanks to the heterogeneity of the works, it was therefore possible to have real-time feedback on the effectiveness of the solutions adopted both during the progress of the same project, and in comparison, with other work at different stages of progress. At the beginning of this work, before starting to put their hand to this project, the students had to face the work path including the application of the various methodologies in complete autonomy. The difficulties encountered were manifold, and mainly linked to the study of the subject, given by its very nature: SDE is an industrial methodology widely used in an innovative business environment, but of which there is very little bibliography and literature. The study is therefore difficult, as it is strongly linked to the continuous comparison with the reference teacher, without which it becomes difficult even to obtain validation of the goodness of the work in the progress between the various steps. Carrying out these works independently can therefore sometimes be detrimental to the quality of the works themselves and also undermining the primary research objective of the University, set in pursuing a constant improvement in the succession of the various projects developed internally.

7. Future Improvements

Thanks to these structures and adequately trained staff, the effectiveness of this work in the students' projects will be tested, comparing the results obtained before, during and after, given that the work of preparing the theses will go on without interruption, thus allowing overall comparisons to be made, as well as in progress.

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