Ecodesign of electronic devices

UNIT 4: Design concept for electronic devices

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Chapter summary:

- Approach to electronic device design
- Functional analysis
- Requirements specification

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4.1. General approaches and concepts of designing electronic devices

Design of electronic devices is a complex process that requires many preliminary preparations and analyses. Part of preparation is consideration of environmental aspects of the design process, production, as well as operational efficiency of the device. The basic procedures of development and design do not change with ecological approaches, but they obtain a new approach that also recognizes environmental aspects and standards. The purpose of ecodesign is improvement of the design process that is already in use for existing devices or design of new concepts that consider sustainability and product functionalities. In many cases, the redesign is a common practice in companies because it has lower risks and the implementation of the product to the market is easier [1]. In the majority, these are improvements of energy efficiency, as well as advanced functionalities of the device. Often redesign with the ecological approach is motivated by new technologies and technological development. Advanced and new technologies bring new components to the market that also meet many ecological standards and are, therefore, equivalent substitutions for the components that are currently in use. To a large extent, the productions is also adjusted to the redesigned products which means that the costs of product improvement are relatively low [2]. Contrary, radical approaches and development of entirely new products are associated with higher risk and good market analysis. In these cases, the device concept is entirely new and is not yet implemented to the market, or it does not even exist. The redesign is the most important in the product's pilot version [3], where the manufacturers want to analyze design processes, production process, and market characteristics. Environmental effects and analysis are thus present in all phases of product design. Research shows that 80% of environmental effects are realized in the early design phase. Due to this, the product developer influences the whole product lifecycle and the opportunity to manage it. The early phase includes selection of materials, technological processes, and the production process as well as the final product. From this point of view, it is very important to design systematically and include environmental effects to the process of development and design.

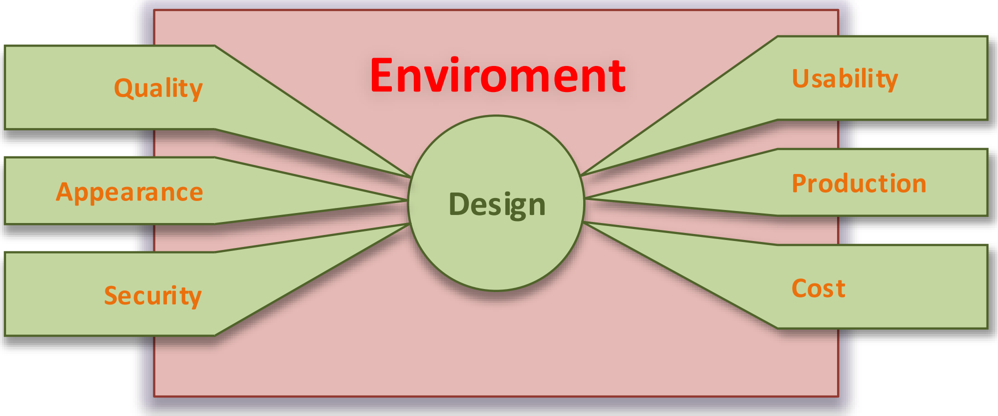

IMAGE 1: PRODUCT DESIGN WITH CONDISERATION OF ENVIRONMENTAL ASPECTS

As already mentioned, the basis of ecodesign is reduction of product's environmental effects in all cycles of development and use. Lifecycle includes different stages that follow in logical order. The process can begin with the acquisition of materials and processing of resources. The next cycles include production, distribution, use, and removal or recycling of the product. In all phases, we can see different environmental and social questions that we should address in the design process. Important environmental factors are used resources and energy [3]. Sources are all input sources, such as water, non-renewable resources, and energy used during lifecycle and all output sources, such as emissions, wastewater, hazardous and chemical waste. Other important factors are radiation, noise, traffic saturation, current pollution, local unwanted weather occurrences (fog, snow, frost). National and local legislative also have a big impact as they impose handling and storage of hazardous and nonhazardous waste. Lifecycle also includes withdrawal and recycling of devices which became more important than production due to a growing number of electronic devices in households. A lifecycle analysis and systematic cradle to grave design or cradle to cradle design lead to ecologically compliant and efficient devices.

Three stakeholder groups participate in the development of electronic products. The first group expresses wish for product development and presents problems that need to be solved. The second group approves design draft and produces the required solution. The third group accepts the recommended solution and implements it. The last group needs to consider given criteria and leads during the implementation process. The image below shows a connection between stakeholders in the design process.

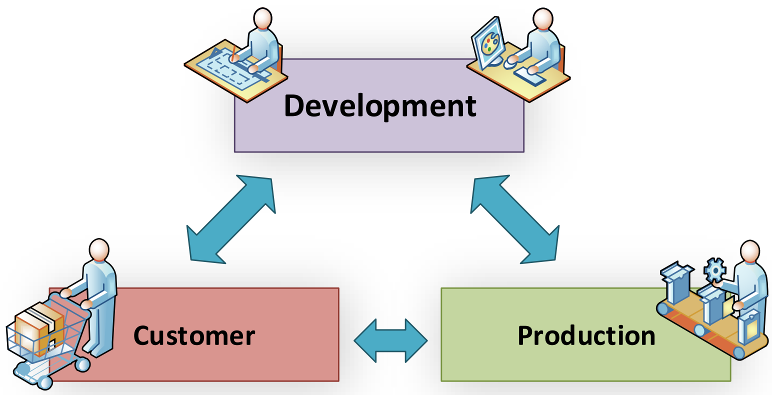

IMAGE 2: CONNECTIONS BETWEEN STAKEHOLDERS

The first group that requests a problem solution or device development are customers or end users. The second group that follows these wishes of the first group, finds solutions and offers the final product concept is a group of engineers and developers. The third group that approves solutions by the second group and implements them efficiently into the final products with the given criteria is production.

Let’s take a look at the relations between three stakeholder groups in the case of a television program distributor who needs to extend their covered area. For the solution of this problem, the distributor employs a development engineer. The engineer develops a problem solution and then hires a contractor. The contractor manages renting and delivery of equipment which needs to meet the given specifications. In this scenario, the developer is essential to the agreement. He defines the problem in cooperation with the customer, develops and presents a solution. Developer acts on behalf of the customer, manages contractors work and controls whether the final product and solution fulfill the needs and requirements of the customer.

The presented model can also be applied to the electronic industry that mass produces large quantities of devices and components. In this case, the marketing in the company knows the customer’s wishes and habits. The marketing department is in charge of market analysis to determine market needs. Then they hand over these analysis results to the research-development (R&D) department, which consists of developers and engineers. Depending on the market needs, they develop their concepts and offer solutions. The third group in larger companies is production that realizes the given solutions. Developers also have the leading role in this group. They communicate with the marketing department to determine the problems and wishes and then after presenting a solution they communicate with production to control the quality and specification of the products.

In the triangular communication of developer’s roles are present two trends. The first is developer’s communication with the customers as well as the production through the whole development and production cycle. Due to this, the developer is forced to communicate with the customers and recognize their characteristics as well as communicate with the production to foresee the final appearance and functionalities of the product. The second trend of triangular interaction is a migration of production from the parent company to the contractors. In this case, the communication is weakened and, therefore, the control and product quality are conditioned by a precise device specification which is secured by a legal contract. The given specifications precisely determine production methods and processes that are defined according to the sustainable and ecological development guidelines.

Technology development has come to the point where complex devices can be produced for a very low price. Although the production is relatively low which is possible due to the new technological processes the complexity of the products on the other hand requires a long and expensive developing process. If we take a closer look at the smartphones, we can see that the production costs are very low in comparison to the price of development. Part of development is not only technological perfection but also functionalities and appearance that attracts buyer's attention. If we combine it with ecodesign, it means that the developers besides all of the above also considers ecological aspects of the device. Often in design, it is compulsory to accept a compromise between ecological aspects and efficiency. For example, the phone is a very common device in everyday life. The more efficient phones with higher calculating power, larger and more powerful displays require higher energy consumption, which is a bad ecological indicator. These phones are also heavier, contain more material, the batteries have higher capacities, etc, which all point to poor ecological efficiency. Today, the electronic device developers are under high pressure, as the technological conditions enable fast production and if development is slow, the product can become outdated or uncompetitive before it even comes to the stores.

Designing of electronic devices requires a structured approach that enables the best control over individual development segments regarding simultaneous activities.

4.1.1 Design process

Most of the design problems are very complex, so it is difficult to predict the final result. To achieve the goal, the developer starts problem-solving methodologically in separate phases. This approach can be useful in different engineer disciplines. As shown in image 3, the design process begins with expressed needs and possible problems and symptoms. The developer presents these needs as definitions with potential problems and predicts the final solution. In this phase, it is very important that the developer considers environmental aspects when creating definitions and predicting final solutions. After the problem is defined, the developer starts searching a suitable solution which is directly conditioned by environmental effects. Searching for a solution in ecodesign is not only related to the final efficient product, but also to the choice of production technology, used components, material types which need to be as ecologically suitable as possible.

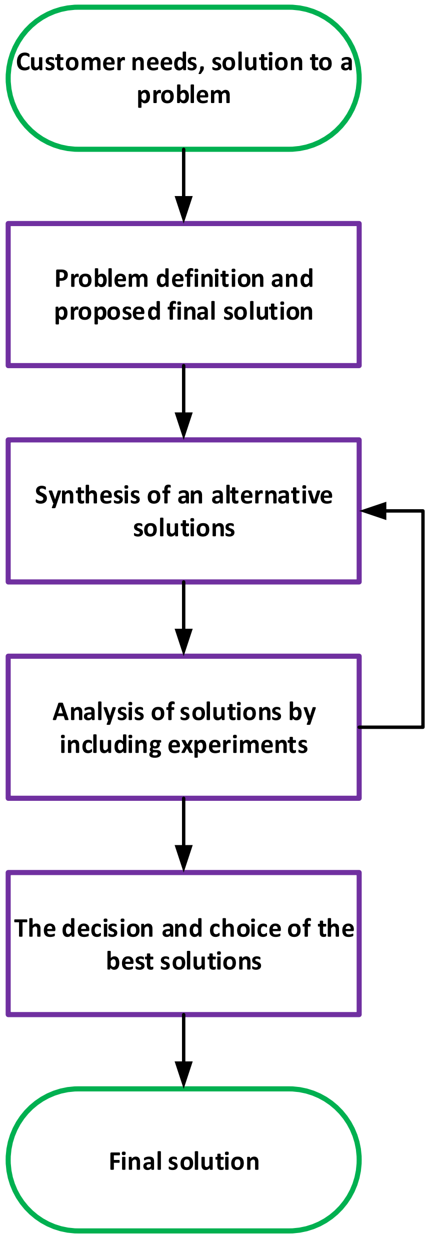

IMAGE 3: DESIGN PROCESS

Ecological devices cannot be of lower quality or less efficient. Contrary, the ecological devices need to be of higher quality and more reliable than competitive products. After searching for the solution follows the analysis and its results lead to a suitable product. When the solution does not lead to a suitable product, design is returned to the stage of finding solution or modification of the existing one. This process is repeated until an applicable solution is found which fulfills the given conditions. In majority, it is recommended that the designer finds multiple solutions that fulfill the requirements. With this approach, it is possible to evaluate the solutions and find the most suitable and optimal one. By all means, it is necessary to think about the development process and costs of solution finding. Therefore, it is important to accept a compromise between the number of found solutions and the probability of the best-selected solutions. The probability of the best optimal solution is increased with the number of found solutions.

4.2. Methodology for high-quality device design

All devices and items can be evaluated based on their qualities or price on the given rating scale. Unfortunately, there are no criteria for measuring design quality and its methodology. Relative efficiency between the two approaches can only be given on the theoretical basis. The subjective comparison of the two approaches is a very difficult task because the engineer problems are multidimensional. Due to this, it is better to focus on evaluating those parts of the methodology that have common points. From this follows that it is resourceful to evaluate design methodology according to the market area. The market area can be divided into industrial and consumer market. For example, the industrial solution has a price that is closely related to the quality and engineering work. Contrary, the consumer market is notable by mass production of devices which leads to a lower price sensitivity according to the invested engineer time and quality. The mass production covers development costs easier as the industrial environment. Generally, quality of products is significantly more important on the industrial than on the consumer market.

For quality ecodesign, it is very important that the product meets high environmental standards both in production as well as in use and removal. In many cases, we face a dilemma between efficiency and saving when designing highly ecological devices. Saving properties are the key factor of ecological efficiency in its operating time. If we look at the example of embedded systems, computer system or smart devices (phones, tablets, etc.). Highly cost-effective devices contain central processing unit (CPU) that operate at higher frequencies which lead to higher energy consumption. When designing devices with certain CPU units, the ecological aspect is seen in software. Quality software does not only equal to providing of high capacities but also savings and rational energy use. The latest technological achievements offer multicore central processing units which consist of cores for normal device operation and cores that are used for complex calculating operations. This is how device management is set up, so certain tasks can be transmitted to different cores. It is important to note, that lifetime of quality products is longer, meaning that less natural resources were used to perform a certain process or service. We can take a closer look at device A and device B, which both perform the same task. Both devices are made of similar materials and have the same weight. Device A has a longer lifetime than device B. In the device A lifetime we need to change two devices B. This means that the same process on device B has used twice as many natural resources as device A. In this evaluation, we did not consider the energy that is needed for removal and recycling of the product. Higher product quality also leads to higher brand trust.

The consumer market is much larger. Therefore, more effort is put into designing products for this market. To this contributes the fact that the consumer market is very diverse and susceptible to different products, but there are also many possibilities for the production of new devices and solutions. The industrial market is significantly less flexible, and in many cases, it is difficult to access for new companies without reputation. In this environment brand trust plays an important role and trust in product quality is even more important than the price. Due to this, we can say that a lot more engineering effort goes towards the industrial devices than to devices for general consumption. On the consumer market, the price is more important than quality, which is usually on the second place.

Good design approach includes ecological approaches and reliability in the early phase, even if the solution is far from finished. In the early design phase, it is very important that the designer evaluates the feasibility of the solution with as little spent time and effort as possible. Only one out of ten suggested solutions leads to a successful end and implementation, meaning that the made efforts and time for the remaining nine solutions are covered with one successful project. The evaluation of time, used for finding a solution and feasibility evaluation is crucial for designing electronic devices.

4.3. Analysis and requirements specification

Designing of the electronic systems can be compared to traveling. Just like in traveling the main task is to determine the destination and route. Unfortunately, this is often neglected. In many cases, designers of electronic devices make a mistake because they do not invest enough time and effort for analysis of the whole problem that they are dealing with. Requirements specification is the first step to designing device and presents the travel destination with the given answers to the questions, such as “What is the problem that we are solving by designing device?”, “What is the design purpose?”. Image 4 shows requirements specification in the design process.

Requirements specification answers other critical questions, for example, “How can anyone included in the design process know what is done?”. This way the specification determines criteria for verification if designing fulfills the set goals. It also describes the tests that will be used for verifying the design process. Requirements specification also provides an important control point for determining the feasible direction of design which is part of the design process from start to finish. It also acts as an early filtration that excludes the design processes that are too ambitious in comparison with others, have contradictory goals, solve unfeasible or persistent problems or in any other way condemned to failure.

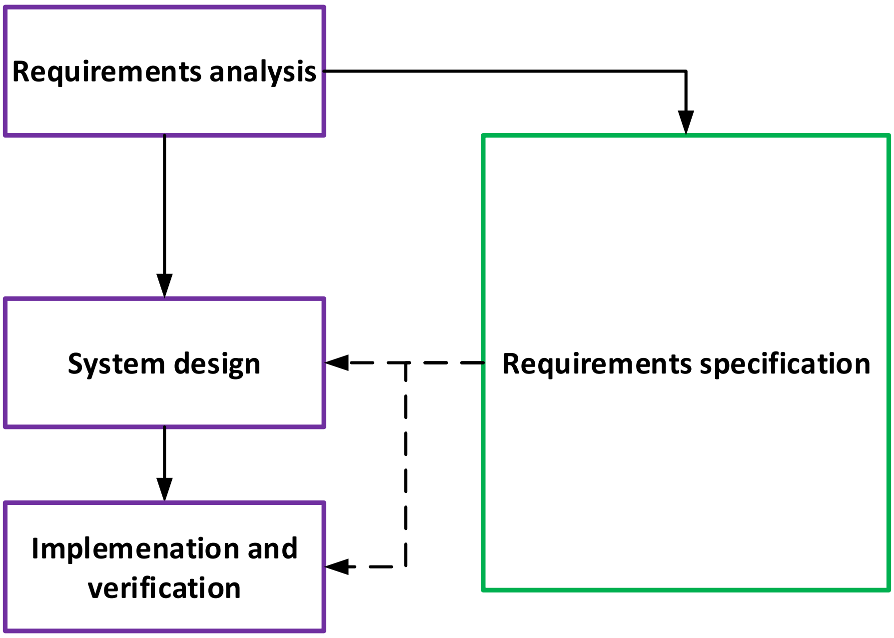

IMAGE 4: REQUIREMENTS ANALYSIS - THE FIRST STEP TO SYSTEM DESIGN

In many companies, less than one out of ten products is commercially interesting can reach market success. As image 5 shows, the design costs grow exponentially during the product design process. Recognition of design approaches in the early design phase that will have poor success in the future or negligible market share will positively affect the business. It is interesting, that a large share of devices that are ecologically oriented have a significantly higher level of opportunities for success, comparing to devices that do not have these factors. Although it seems irrelevant, development of requirements specification demands time, money, knowledge and to a great extent an experienced engineering judgment. The process of determining requirements is also difficult, because certain analytical skills are needed which differ significantly from the classical engineering curriculum taught in school.

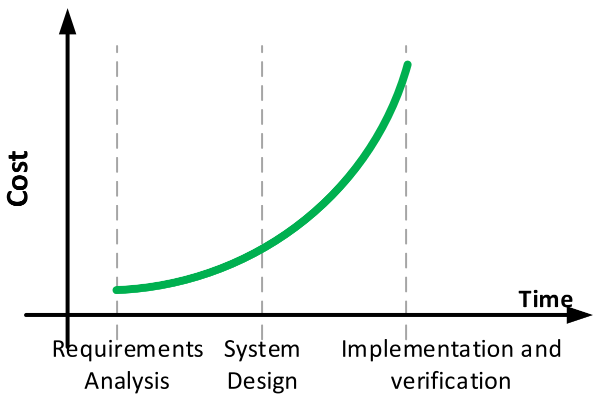

IMAGE 5: DESIGN COSTS IN RELATION TO TIME

4.4. Determining and outlining requirements specification

At this point in the design process, the emphasis is on the customer that needs a solution for their problem. The engineer's concern is not only solving the given problem but also understanding the problem source. The goal is to clarify, define and determine the criteria for design which need to be stated in the requirements specification. Important engineer decisions are made based on experience, expertise, and information and not only on purely engineering calculations. It is necessary that the decisions are made in co-operation with the customer or buyer. The data is gathered from the customer and many other sources. Data gathering is organized, so that customer needs are checked for compliance, and then the data is sent back. All suggestions and possible alternatives need to be defined regarding high compliance with the design process and need to be very clear and precise. As already described, the customer can appear in different design phases. The consulting engineer has direct contact with the buyer and the customer. In larger companies, the consulting engineer is also in contact with other company sectors, such as marketing and development departments. No matter who is the buyer, the designer needs to be willing to work as a consultant, mentor, expert and attentive listener. This is a complex task. Therefore, it is usually assigned to the most experienced and mature engineers in the design team.

4.4.1 Two scenarios for determining requirements specification

In the development of the specification of requirements, the role of engineer differs depending on the nature of the problem, expertise, buyer's experiences and the amount of information that can be used in the task. For a better understanding of development of the requirements specification, the processes can be presented in two scenarios.

The first scenario is named the informed customer. One example is an engineer, who is hired by a transport-logistics company that wants a computer-aided dispatch radio system. The problem characteristics are presented in table 1. In this case, the customer consists of multiple individuals, manager, operators, and drivers. All stakeholders have a lot of knowledge and information about application development. They have in-depth knowledge of business and distribution of vehicles and know exactly what they want to achieve with this application. In this way, the information is accessible from different sources. In the given example, the sources of information are manager, operator, and driver. They can deliver data, such as number of vehicles, frequency, and number of sent messages, financial reports and forecasts. In this case, the buyer will have expectations on application functionalities and price. Due to this, the buyer can look up to competitive companies that already use this system. With this approach, the buyer will deliver data on system capacities, wishes on how the system should be done, operation requirements, and price. In this scenario, shortage of data is not a problem. Depending on the time spent, price and expertise of the buyer the development of requirements specification are the most efficient and the shortest with the informed customer. Often the given problem is a variation of previous solutions so that the requirements specification can start in the later development phase.

	Informed buyer	Uninformed buyer
Knowledge of the buyer's problem	A deep understanding of the problem and clear development expectations.	Weak understanding of the problem, without experience from the field.
Available information	Immediately available information: • customers • competitors • equipment supplier • similar solutions • publications, books	Limited information. Devices do not exist on the market. No similar solution or approach to solving the same problem.
Development of the requirements specification	Relatively simple with slight effort and costs.	Relatively high demands for effort and costs. Additional research on potential users and cost evaluation are often needed.
Probability of transition to the next phase of development	Relatively high transfer coefficient to the next development phase with minimal risk.	Relatively low transfer coefficient to the next phase. Risks are related to the unexpected complication and price eligibility.

TABLE 1: FUNCTIONAL REQUIREMENTS CHARACTERISTICS IN INFORMED AND UNINFORMED BUYER

The second scenario is for completely uninformed customers who represent a complete opposite to the informed customer. The term uninformed customer means that the requirements specification is an unexplored field. Such example is a company that designs terminals for mobile payments through the mobile network. The terminal works for all mobile phones in all networks. Design, appearance and terminal functionalities need to be as simple as possible. One example is appearance and functionalities design. The terminal needs to be small, so it can be mounted on different vending machine and be easily understandable. The biggest problem of designing devices is its usefulness and how to use this device correctly, so the payment process is as fast as possible. Mobile payments are still a new payment method. Therefore, it is necessary to educate users how to use the system or enhance the instructions with images next to the terminal. The terminal and phone transfer data through a communication channel meaning the terminal can be used with all phones from different manufacturers, operating system, device age, etc. The most important technical part and the application use are connection of the phone's microphone to the terminal's headphone jack, and phone's headphones jack with terminal's microphone. In case of bad connection, the payment process needs to be repeated which can cause customer frustration and extend transaction period. The company has invested a lot of effort and money to develop functional requirements regarding the terminal design, such as appearance and usability, as well as solving of technical restrictions. A lot of information was obtained from customers who were tested with various means and methods. A large part of the engineering approach also requires ecological approach, meaning the device needs to be compliant with ecological directives that are currently in use in the Europen Union.

To a large extent, development of functional requirements is a combination of both approaches of the informed and uninformed buyer. It is important to define what type of buyer is our customer because the development approaches differ in intensity and costs of developing the functional analysis. It is also important to determine whether it is possible to apply alternative solutions to new devices.

IMAGE 6: TERMINAL FOR MOBILE PAYMENTS

4.5. Two-step approach to developing functional specifications with ecological factors

Development of functional requirements requires an approach that significantly differs from approaches that are being taught in the education process. The task of functional requirements designer is not proposing alternative solutions or rejecting some approaches, neither is their task to analytically calculate parameters, but to suggest optimal solutions. The optimal solution is one that is a compromise between the given criteria. The given criteria can be device functionalities, device appearance, technical solutions, used technologies, final solutions costs and production costs. An ecological perspective is a classic approach. Requirements specification also includes proposed materials, production location, logistics-resources suppliers, high level of recyclability and the lowest possible carbon footprint.

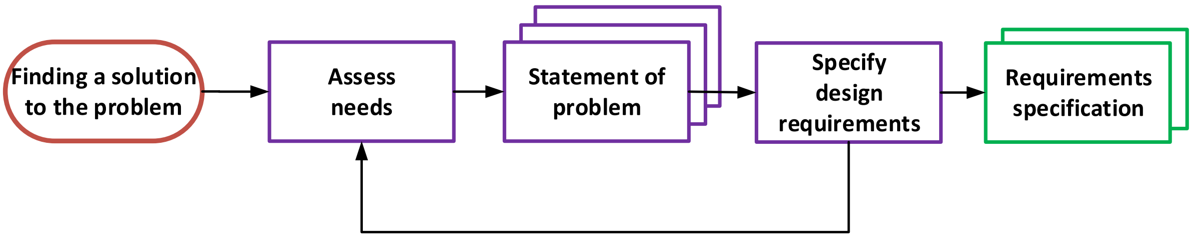

IMAGE 7: TWO-STEP REQUIREMENTS SPECIFICATIONS DESIGN

Image 7 shows the development of requirements specifications that is split into two steps. The first step evaluates buyer's needs and defines the next step for assessment of needs that we need for solving the problem. This report needs to be prepared in the buyer's language, meaning it usually does not contain technical terminology and needs to be easy to understand.

The second stage includes a detailed report on the problem with additional technicalities on possible solutions. This report contains technical terms and is intended for the engineering team and developers. The second stage determines criteria for evaluating model acceptability. The criteria are also used for choosing the solutions and designing alternatives. With criteria it is possible to determine whether a solution is acceptable or if it would be better to use an alternative. In the end, criteria are used for evaluating if the design meets the set goals.

The key characteristics of developing requirements specification, presented in image 7, is the feedback line that returns current conclusions to the stage of reconsideration and reevaluation. The feedback line means that after problem specification is defined the same questions is reopened to see if it fulfills buyers needs. This is similar to when the buyer has additional needs, and it needs to be determined if the solutions fit the problem. For the cyclic development of requirements specification, it is necessary that the developer decides freely, makes agreements with the buyer on next steps and corrects previous decisions when needed.

The result of this process in the image 7 is a functional requirements specification document. This document is a short report on how device realization will be achieved and how to evaluate the final design. This document answers two key questions: "What will the design team do?" and "When do we know that the design is finished?". The included formalities in the requirements specification vary depending on different circumstances. This can also be an agreement between the marketing and engineering department in the same company. Some companies give higher importance to formal procedures that are required to obligate the development team to monitor and develop product design. In companies that hire external partners or contractors for designing devices, the requirements specification can serve as an official appendix to the contract between both sides. When it is part of the formal documentation, it is very important that both sides authenticate the specification. Regardless if the specification is formal or informal, it presents an agreement between the manufacturer and buyer of the electronic device.

4.6. Evaluation of realistic circumstances in device development and design

Before we present the requirements specification in detail, we have to examine the evaluation of realistic circumstances in the design process. Quite rarely the developer team finds themselves in circumstances where design guidelines are very clear and simple. In a realistic situation, the developer team has a limited development space. All these limitations need to be soon recognized and noted from the beginning in the functional requirements, so they can be addressed in the following design stages.

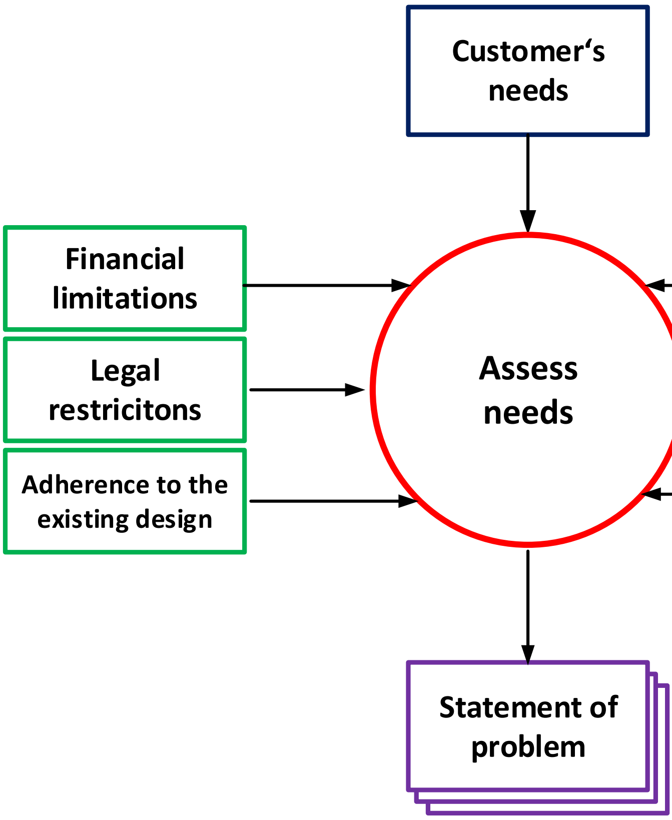

IMAGE 8: EVALUATION OF REALISTIC CIRCUMSTANCES IN DEVICE DESIGN

Until this step, only customer's wishes were considered in the development of functional requirements. A deeper consideration of other effects would exceed the functional requirements and would have a very little effect on content understanding. Nevertheless, it is important to be aware of these limitations. Image 7 presents the typical effects which developer needs to consider and define as possible or limiting factors. As already mentioned, inputs in the system are customer's needs. Here is a short list of non-obvious effects that influence product design. These effects expand the design opportunities or only restrict them.

1. Experience: Experiences to a great extent accumulate in the developer team. In many cases, external sources or experts from a specific area are also included. Sources of experiences are technical literature, consulting, expert's instructions, and buyer's experiences. Especially in large companies, experts from other departments or consultants from subsidiary companies are listed as external sources or experience

2. Similar solutions: Examples of similar design, sometimes even competitors, show design journeys or how others have addressed the problem. Registered patents and their research play an important role in this process. By researching registered patent, the designer can verify if the problem was solved and how. This way he can obtain a lot of information on the development process and problem solution.

3. Research: Important part of research is also the primary research of customer needs and financial market. The customer, who ordered the device and developer need to be familiar with at least the basic device specifications, target users, and market. This information can be obtained with research.

4. Financial limitations: Two very obvious design limitations are either the financial ability or readiness of the customer. His expectations on development costs can significantly limit or undermine development.

5. Legislative limitations: Apart from technical and financial limitations, legislative and political influences can also limit device development. In European Union, many rules and laws are in use to improve causality and device safety. All laws, related to environmental protection, monitor that the electronic devices are of highest quality, have high efficiency and affect environment as little as possible. Environmental effects are present in the production process, as well as when in use and in the recycling process. Detailed laws and restrictions are presented in the following chapter.

6. Compliance with the production capacities: Mostly, design is related to modification with the intent to improve existing device characteristics. Completely newly developed products need to be included in the existing device lines. It is important to consider that the new product will be manufactured with the current devices and processes. Many companies hire developers at the same time they design products and prepare technological process. Management and financial departments significantly affect the used technology and software in the developed device.

4.7. Analysis of customer needs and determining the problem

Analysis of customer's and buyer's needs is the first step to understanding requirements and design development. The analysis starts with the customer and leads to non-technical problem definitions which would be solved with the design. Problem definition has to include the following aspects.

Non-technical aspects: The problem has to be addressed in customer's language, meaning it does not contain unnecessary technical terms and jargon.

Non-quantifying definitions: Specifications, such as dimension, quantity, price do not need to be presented in a numerical form. The needs can be presented qualitatively.

Final aspects: In all possible extent, problem definition has to include all aspects and problems that the designer can come across during device designing.

Identifiable aspects: Problem definition is subjective and has to be aligned to the precise quantitative requirements specification. It is often possible that customer's wishes are included in the quantitative requirements specification.

Below, we will present techniques that can be used in the requirements specification. Use of different techniques depends on the circumstances and mode of device design. It also depends on previous customer's experiences. These techniques will be presented as a set of methods and techniques which can be used individually or in combination with other techniques.

4.8. Questionnaire

Articulation of needs and wishes is very dependent on previous knowledge about the problem and customer's experiences. The designer of devices for the broad market and large-scale production has to cooperate with the marketing department, which needs a study and market research on device launch. The study includes research and user's experiences with the product line. The crucially part of cooperation with users is an investigation which benefits and novelties need to be present in the device. The marketing department also has prepared estimations regarding product packaging and price. The developer often has to take the initiative in user communication and answering their questions, so they can increase product usefulness, increase reliability and simplify maintenance.

Use of a different set of questions and queries can be seen in designing and developing hydro generators. These projects often do not have any contact with average users in everyday tasks and communication, and query only take place between developer and engineer who has experience with installation, maintenance, and handling of hydro generators. Often the people, who maintain and control the system through applications are a rich source of information for development and upgrading of the device.

Although questions for the users can vary depending on the problem, the questionnaire for users and buyers is a basic tool for the developer. Table 2 shows some general questions that developers usually ask the users. Direct and targeted questions are usually more productive than broader questions. Advanced questioning techniques, such as asking a set of questions where certain questions inquire about the problem that the developer wants to get acquainted with. If we take a look at a designer of a device that will be produced in large quantities. Designer wants to learn as much as possible on device reliability. A direct designer questioning would be; "What reliability do you expect from this device?". Such questions would give relatively poor information on reliability. The question can be modified to: "What is the percentage of similar products that were impaired during the warranty period?". The following questions could be: "Is this acceptable for your or would you want this device to be more reliable?". More precisely, "We are capable of improving device reliability from 95% to 99% with a double increase in production costs. Is this acceptable to you?".

Questions that define design problems:

- What is the problem that needs to be solved?
- Why does this problem occur?
- What is designer's role in problem-solving?
- How do I know that I solved the problem?

Questions that define environmental aspects:

- Which environmental aspects need to be met with the device?
- What technology is used in production?
- Recycling process and a possible share of device recycling?
- Choice of electronic components and materials?

Questions that define time limitations and budget:

- By when does the problem need to be solved?
- What is the highest permitted designing price?
- What is the expected price of mass production?

Questions that define reliability and maintenance:

- What are consequences of device failure and probability of it in the timeframe?
- What is maintenance price (service personnel, spare parts stock, warehousing)?

Contractual issues:
• How to determine the end of product design? • When are the design results still acceptable? • How is it going to be paid? • Is development process legal?

TABLE 2: EXAMPLE OF USER QUESTIONNAIRE

4.9. Different needs and wishes

Definition of user's needs is a complex and demanding task. Obtaining of information requires many iterations and repeated questionnaires to acquire a high number of different options. A very important trait of examiners is differentiation between user's wishes and needs. The developer can inquire about user's wishes for the marketing department to learn which novelties that should be included in the new device. The answer is very simple. The device has to be more advanced that competition and cheaper for manufacturing. This is a simple expression of user's wishes, that is often conflicting.

User's needs and wishes are presented in image 9 as two overlapping rectangles. The fields are of different sizes and are not aligned (A, C). User's wishes (C) often overlap with the needs (A). If problem definition is designed so that it considers only user's wishes instead of needs then the design will not correspond to the needs. Firstly, the design would not fulfill all the needs, meaning the approach would be insufficient. Secondly, unnecessary wishes would lead to a higher device price. To sum it up, designing would be wasteful and would not fulfill all the needs.

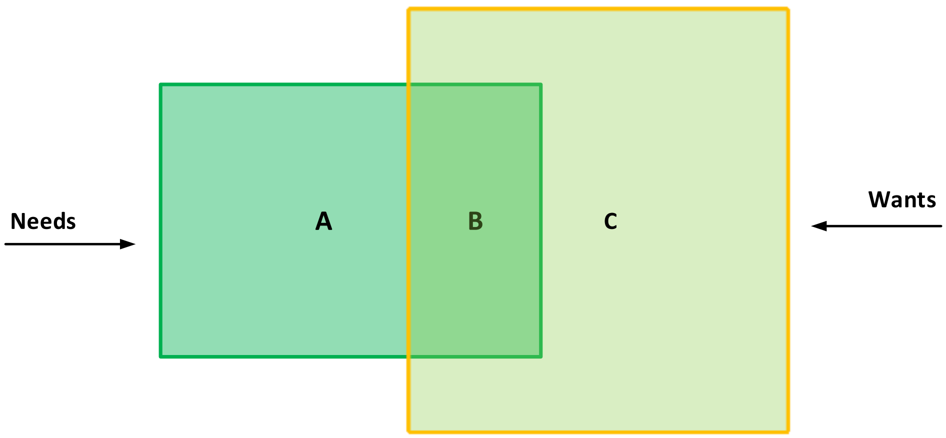

IMAGE 9: DESIGNING THAT FULFILLS WISHES INSTEAD OF NEEDS IS REFLECTED IN INSUFFICIENCIES (AREA A) AND UNNECESSARY ADDITIONAL FUNCTIONALITIES (AREA C).

Designer's task is to translate user's wishes into problem definitions that reflects real needs. As shown in image 10, there is a high probability that the problem definition will not fulfill all the wishes. Designer's task is to get closer to the needs as much as possible. Being careful and precise in problem definition is paid off in the next design phases.

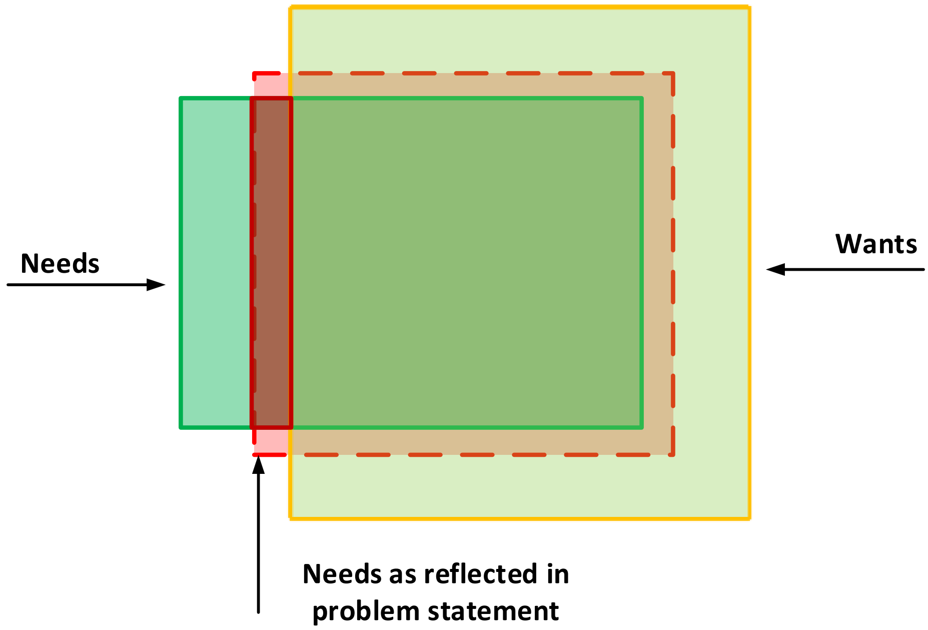

IMAGE 10: MATCHING OF PROBLEM DEFINITION WITH THE REAL NEEDS LEADS TO OPTIMAL DESIGNING.

4.10. Determining project limitations

External factors can influence limitations of alternative solutions that the designer predicts during designing. Essentially, some solutions are outside of the project capacities. Definition of project limitations is an effective approach, used for defining what designing cannot include or contrary, what needs to be included.

In the previous chapter, we have presented the term "informed customer" in the case of a logistical company. In limitations analysis and research, it is very important that the developer considers the number of company vehicles, ways of communication with the dispatch center, how many messages need to be sent to each vehicle, etc. In technical limitations, we can also consider the further development, predicted growth, how many vehicles can be added to the existing system as project limitations. From the perspective of high ecological awareness and related quickly growing stricter laws in all EU countries, it is reasonable to predict future trends and guidelines of ecological politics. Lots of efforts need to be invested to guarantee the system to be modularly developed. Modularity enables faster adaptations and system adjustments regarding new standards and technological development. Considering all aspects, the key roles are maintenance and options for upgrading. Modularity is much appreciated in this case as well.

Current system is very often the limitation of new projects. Many times, user's or buyer's wish is for the new system to be similar to the old one or to be within the certain frames. The entirely new system requires re-learning of users, which slows down adaptation phase and system launch with full functionalities. The essence of upgrade and redesign is precisely in using newer technologies that often can not meet the functionalities and similarities of the old system.

Lastly, there are also legal limitations and regulation. For example, a logistical company that is trying to establish a wireless communication system has legally prescribed limitations regarding transmitter power and frequencies. It is also defined what type of antenna can be used. Device legalization must not violate any law regarding copyrights and patents. Designer's task is to consider all these criteria and include them in product development.

4.11. Input-output analysis

Designing problem is conceptually presented as a functional block with given inputs and outputs. This problem presentation gives the designer a clear view on what issues need to be solved during designing and what is the purpose of designing.

For example, take a look at designing of gas flow control devices with a multichannel laboratory measurement systems. The gas is transmitted from the pressure tank to the output nozzle for each channel. The nozzles are connected to the control valves and flow sensors. Machine operator regulates and adjusts flow values for individual channels separately and the bucket pressure as well. Current flow and pressure values in the tank are displayed on a graphical interface.

The next image - image 11 shows the input-output diagram of the flow meter of the measuring device. When designer and customer create this diagram, it is highly possible that they discover unexpected problems. For example, they can look deeper into what calibration methods will be used, how they will adjust the values, which alarm types are needed, etc.

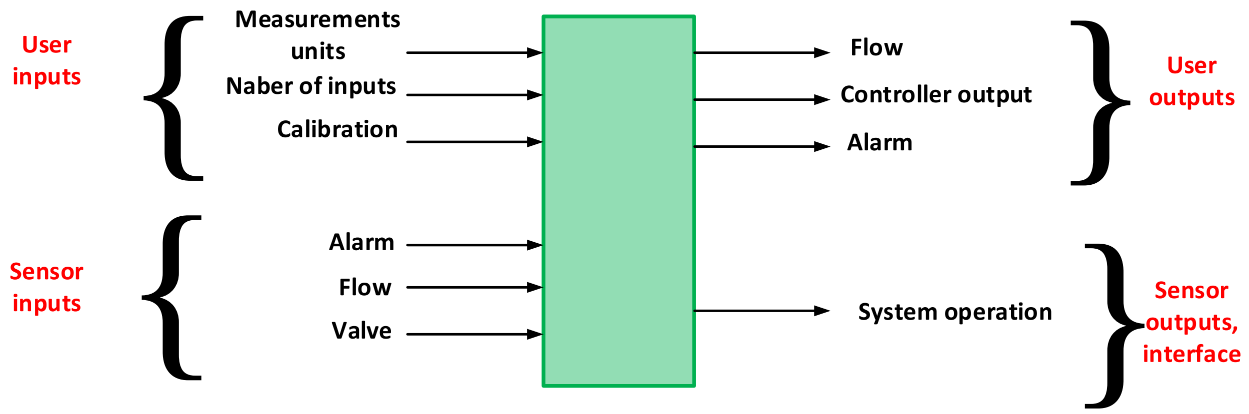

IMAGE 11: INPUT-OUTPUT DIAGRAM

The input-ouput diagram is also useful for determining functionalities in complex and demanding projects. The diagram does not determine non-functional requirements, such as size and reliability.

4.12. User interface overview

Most of the electronic products exchange user data through the user interface. Data exchange between the device and user takes place in different ways, such as: through a keyboard, sound, display, etc. User interface and type of device interaction are key in launching requirements specification. Therefore, it is crucial for the user interface to determine requirements specification. In most cases, the developer needs to put himself in the user's role. Some devices require more user interfaces or different device interaction types.

For example, take a look at the development of a smartphone. The interaction between the device and user mostly takes place through the touchscreen display. In the perspective of high phone efficiency (autonomy) the device needs to be designed in an energy saving way. Research shows that a large share of energy is consumed by phone displays, therefore, they turn off after a certain inactive period. Most phones on the market have external keys besides the screen that are intended for vital functions. Vital functions are on/off key, fingerprint sensor, volume control keys, etc. Every smartphone also has a speaker that not only serves for talking, but also as an alarm and notification on device conditions. All functionalities and user interface have to be noted in the requirements specification. From the ecological efficiency perspective, energy saving is key for reducing the carbon footprint of the device in operating phase.

4.13. Research of design attributes

Many design processes have similar or identical characteristics. Research of design attributes can help reveal additional project needs. It is very sensible to divide the attributes into functional and non-functional requirements. This approach to attribute description leads the designer to a clearer overview of what design is trying to achieve (functional requirements) and what should design look like (non-functional requirements).

For example, take a closer look at a mobile phone designer. The mobile phone market is very saturated and competitive. Mobile technologies are fast growing and due to this new products require new improvements, better functionalities and use of new technological solutions or advances. The designer is faced with the decision what functionalities the phone should have included and which technological solutions and approaches he will use.

When researching attributes, the designer can discover new design procedures. This triggers a new wave of questions on design needs. In the following table, are presented device characteristics and possible questions that occur about them.

Functional requirements	
Standard functions	Which standards does the product have to fulfill? If the product has to fulfill multiple standards, are these standards set in production, trade or at the customer?
Advanced functions	Which new functionalities does the product need in addition to the existing ones? Which functionalities does the product have to have to compete with the competitors? Do we need any new functionalities? Can the functionalities be categorized as needed and do they depend on the final device price?
Non-functional requirements	
User interface	Will we use new appearance?
Packaging	Wil sizing and weight stay the same? What are the competitors' plans? What are the environmental factors?
Battery	Does the battery need to be upgraded to offer higher autonomy and charging time?

Production	Where can we manufacture the device and what environmental effects will this process cause? Which production techniques and testing will be used?
Reliability	Is the warranty period acceptable? Does device reliability prolong with increased production price?
Service	Is there a need for new service procedures and tools? Is it possible to keep the service personnel?

TABLE 3: FUNCTIONAL AND NON-FUNCTIONAL REQUIREMENTS

The first row in the table above (standard functions) lists questions regarding standards that need to be met. The set standards also influence design methods and determination of requirements. Other requirements are derived from the existing approaches and influence the comparison between the existing and new design. This comparison is useful as it shows starting points od designing new device. Some of these characteristics are production, reliability, and service, which all need to pass design requirements in the design process. These are useful also as further engineering questions and show a tendency to cooperate with other departments or external companies.

4.14. Determination and recognizing of conflict situations

In many cases, we encounter conflict situations in the product design process, especially when buyer's and designer's requirements do not overlap. Solving of conflict situations often leads to a compromise with different requirements. It is very important that the conflicts between the customer and designer are resolved. An agreement between both parties leads to a clearer view of the problem and avoids ambiguities and indecisions.

A common conflict is regarding price, capacities and execution time. The customer usually expects faster capacities, additional functionalities, minimal price and the shortest possible execution time. Communication and customer notification are very important in case all criteria cannot be achieved.

If we again take a look at smartphone design, the conflict arises between functional and non-functional requirements. In the given example we can see that packaging requires smaller devices while higher capacities require higher battery capacities, which also means higher weight and increased device dimensions. The conflict can stay unresolved until technology progresses and improves battery capacities which leads to a conflict regarding price increase. Other possible conflicts are presented in image 12 and 13.

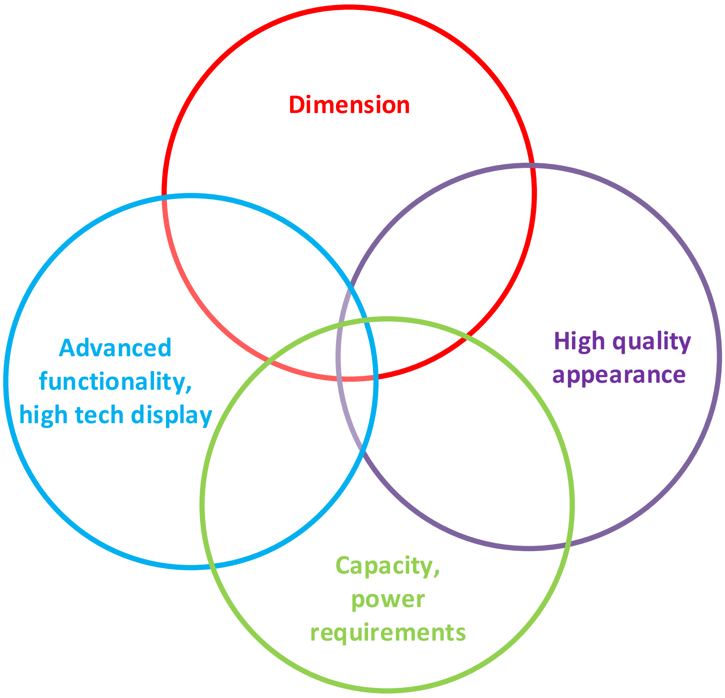

IMAGE 12: AREAS OF CONFLICT SITUATIONS AND REQUIREMENTS

	Size	Battery	Display	Capacity
Size		++	++	-
Battery			+	++
Display				--
Capacity				

++ very correlated
+medium correlated
- medium uncorrelated
- - very uncorrelated

IMAGE 13: CORRELATION MATRIX OF OVERLAPPING REQUIREMENTS

Techniques for detecting possible conflicts are based on correlation matrix shown in image 13. With this matrix, we can identify potential overlapping of requirements and discover their connections. It is very efficient if we use fewer attributes in design, as the matrix becomes complex and correlations are difficult to be recognized. On image 13 we can see that by raising battery capacities we also raise capabilities and drastically influence device sizing. It is possible to present possible conflict situations in the matrix that occur while designing. Conflict situations also occur when problem specifications overlap, which needs to be solved or noted as designer limitations. It is crucial that the customer is notified because they can acquire a realistic overview of the development process.

4.15. Preparation of user instructions draft

Each electronic device has to include user instructions. As with all design methods, user instruction drafts force the designer and customer to determine designer needs and requirements. The following table presents chapters of user instruction draft for laboratory testing machine for managing reference air flow through liquids.

Product overview
Installation 1. Flow sensor 2. Linear valve 3. Linear valves control 4. Microcontroller 5. Communication interface 6. Charging **First launch** 1. Sensor arrangement 2. Calibration 3. Testing 4. Device connection **Operating** 1. Choosing matrix system 2. Obtaining data 3. Alarms 4. User interface 5. Management launch 6. Communication

Maintenance
1. Standard maintenance 2. Troubleshooting

TABLE 4: EXAMPLE OF USER INSTRUCTIONS FOR LABORATORY MEASURING MACHINE

Preparation of instruction draft leads to new questions on designer needs. It is very convenient if the draft is prepared together with the customer who already has experience with a similar device. For example, for designing flow sensor, it is essential to prepare communication protocol and plan on use of computer system, etc. User interface description can be used as a concept or be described in user instructions.

As already mentioned, analysis of design problem is mainly non-quantitative and non-technical, as it only presents what do we want to achieve with the design. With the establishment of designer needs together with the customer we can move to the next phase. The next design phase describes how to move from problem analysis to functional specifications which are more technically oriented and contain certain approaches and solutions. With a good design problem analysis, it is relatively easy to skip requirements specification. In some cases, move from functional specification requires effort, experience, subjective tests, and research. For example, take a look at laboratory machine for measuring flow. From problem analysis statement it is specified that management has to be precise, quick and reliable. The engineer needs to convert this data to functional specification, meaning management error must not exceed 0.5% of desired value and system load time has to be less than 2 seconds.

4.16. Functional specification

Converting of problem analysis into functional specification is a one-on-one translation. Each design requirement is translated to a functional specification. Good problem analysis enables a complete and consistent translation to functional specification. Complete problem analysis is done when design is thoroughly studied and analyzed to perfection. In this analysis there are no contradictions between different design needs.

If analysis is superficial and functional specification is developed, it is very important that designer reviews it together with the customer. In this case, some uncertainties can be removed, and other designer requirements can be determined.

When translating requirements, designer relies on his expertise and experience. It is not expected that designer is an expert in all development areas. Therefore, we have offered different approaches to the translation of problem analysis to functional specification.

1. External expert: these sources include external experts, industrial standards and other sources, such as books, magazines or textbooks. In some cases, external experts act as consultants or external assistants. For example, take a look at flow sensor that has to operate in a determined zone and under different pressures. In the functional specification, measurement and operating zone of the sensor need to be recorded. When the main designer is an electrical engineering expert they need an external expert for tires and hydraulics. The second expertise originates from standardization area. Often standards determine functionalities and process of device design.

2. Analysis of similar systems: The term *reverse engineering* is a common approach. It often has a negative connotation, as it is connected to idea theft and plagiarism. The fact is that most designing is based on previous designs. Until patent laws are not broken, or unauthorized duplication or idea theft occur, this approach is completely acceptable. For example, in smartphone batteries, the functional specification gives a charging time of an empty battery. For determining charging time, the designer has to review characteristics of other devices, made by different manufacturers.

3. Conducting tests or experiments: If we want to determine battery charging time, numerous experimental tests need to be conducted. The designer has to conduct multiple tests of different battery types by different manufacturers, so he can statistically determine the charging characteristics. It is also important to test different charging electrical circuits to determine the most suitable one. The same applies to other system components. Often designer creates prototype devices, circuits, and software that are tested under different conditions and are often conducted in development laboratories.

4.17. Specification of device interface components

As previously mentioned, user and other interfaces between the user and the device or between other devices need to be completely and precisely determined in the requirements specification. All switches, indicators, computer displays, input units, which are needed for interaction with the device, need to be clearly defined. Requirements specification has to also include a draft or an approximate sketch of the user interface.

Apart from the user interface, there are other interfaces that are also very important. Let's take a look at the laboratory machine for leveling air flow through the liquid. The important interface in this machine is also communication module that communicates with the personal computer. Transfer speed and communication type between devices need to be determined. Cross-section of air pipes and interfaces for installation of pipes for flow sensor also need to be defined. Just as important is the choice of flow sensor or if it has digital or analog output. Other important parts are: connect of the sensor to the microcontroller, determination of management type for the proportional valve, how the valve needs to be connected to the sensor and air supply. Similar steps are used with other devices. In a mobile phone, interfaces are more complex. It is needed to define network type and the frequency band for mobile telephony. Today's phones have basic functions, but also other interfaces, such as WiFi, NFC, Bluetooth, GPS module, different measurement systems, such as accelerometer, gyroscope, compass, pressure sensor and distance sensor. We must also not forget the main charcteristics, such as display type and site, camera, fingerprint reader, etc.

4.18. Excessive requirements

In an analysis of needs, it is important that we determine and analyze real customer's needs. When analysis of need is converted to requirements specification, it is crucial that we get closer to the needs and requirements of the customer as much as possible. The specification must not be too ambitious or too inaccurate.

Requirements that are excessive and surpass the real requirements often lead to more expensive device design. An experienced designer classifies excessive requirements into two groups. The first group of requirements are requirements that are not needed. The second are requirements that are too strict.

Usually, the customers have a mindset that small additions to the device do not increase development price to the extent that it would be too expensive, especially when it is software. Although device price does not increase significantly due to additional hardware components, it is important to consider that design costs do increase. On image 14 is presented the exponential increase of design cost depending on adding of different device functionalities.

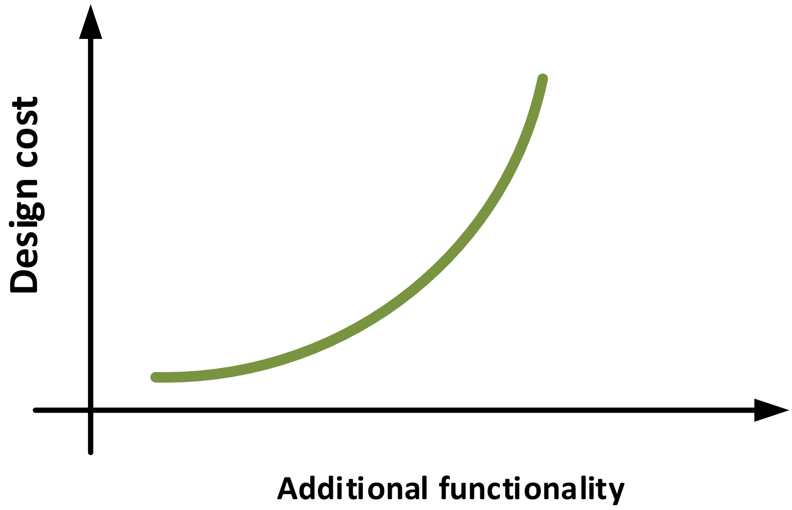

IMAGE 14: CORRELATION BETWEEN DESIGN COSTS AND ADDITIONAL FUNCTIONALITIES

Design costs are increased not only due to additional designer's work, but also due to additional project management, documentation, and device testing.

Too strict or too loose specifications can also drastically increase design costs. Due to improper specification, there is not enough maneuvering space for additional adjustments or, contrary, there is too much space, and consequently, the choice is too undefined and not optimal. Too high requirements for device reliability also influence price. In image 15 that present price growth due to reliability is visible a dividing between a drastic increase and moderate growth of development costs.

If the buyer set a requirement for the device to be highly reliable, then he needs to be notified that design costs are significantly lower, if criteria are partially lowered. All options and design analyses need to be considered when determining requirements specifications.

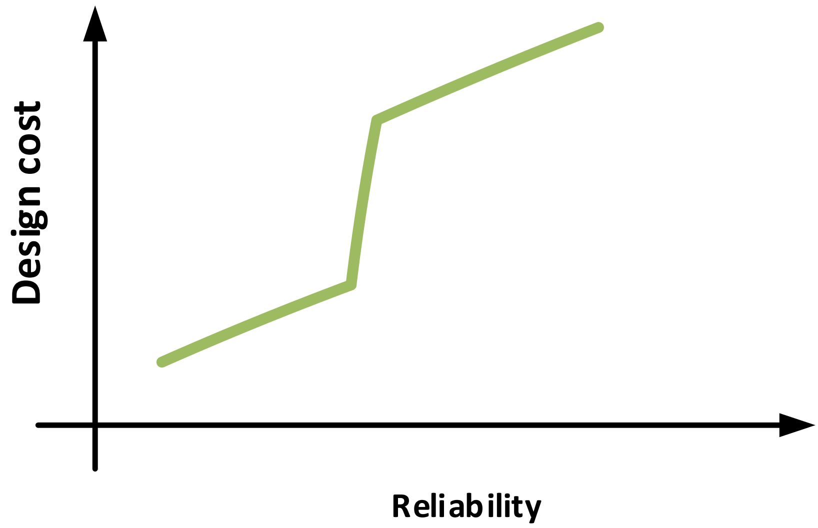

IMAGE 15: DEVICE PRICE IN RELATION TO REQUIREMENT OF RELIABILITY

4.19. Verification

In the phase of verification of needs and goal planning, it is crucial that both sides implement the step. This phase is named *confirmatory test*. It is also sensible that the testing phase does not start before verification is confirmed. This can be achieved with a preliminary testing plan together with the given requirements specifications.

A simple rule is used if designer needs cannot be confirmed then they cannot be noted in the specification. This means that if an unwanted requirement is included in the designer needs then it has to be excluded or modified during verification. It is crucial that design needs are verified while specification of needs is prepared. When individual parameters in specification of needs are determined, the designer has to evaluate if it is possible to perform the verification.

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