Requirements Definition

Design Process

	Design Step		Action	Outcome
Initial Problem	Problem Definition		Surveys, Case Studies, Action Research	Explicit Problem Defenition
	Requirement Definition		Surveys, Case Studies, Action Research	Quantitative & Qualitative Requirements
	Design & Development	Development Design Candidates	Creative Methods, Innovation	Mockups / Rapid Prototyping
		Select the Best Design (Solution)	Optimization	Primary / Secondary Design
		Construct a Prototype	Machining / Rapid Prototyping	Artifact / Fully functional System
	Demonstration		Experiments, Case Studies / Action Research	Demonstrated Prototype (Basic Functionality)
	Evaluate		Experiments, Case Studies / Action Research	Evaluated Prototype (Meeting Requirements)
	Reporting		Summary of the Design Process / Lesson Learned	Final Report
	Redesign			

Requirements - Definition

What type of artefact can be a solution for the explicated problem?

Which requirements of this artefact are important for the stakeholders?

- Requirement (Definition) - A requirement is a property of an artefact that is
  - Deemed as desirable by stakeholders
  - Used for guiding the design and development of the artefact.

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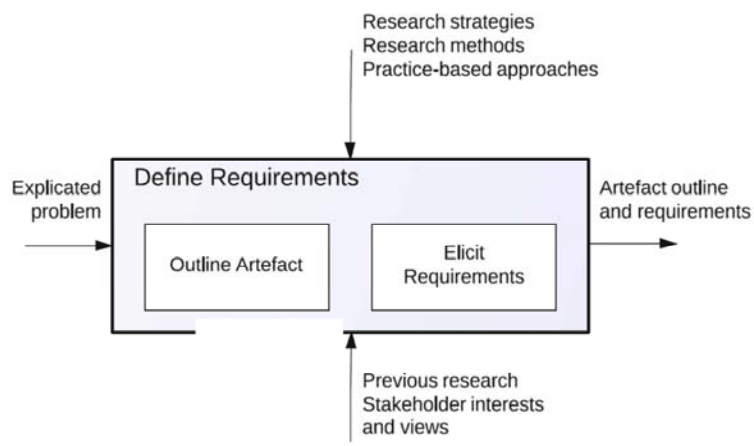
The second activity of the method framework is Define Requirements. The goal is to identify and outline an artefact that can address the explicated problem and to elicit requirements on that artefact. In other words, the activity addresses the question:

What artefact can be a solution for the explicated problem and which requirements on this artefact are important for the stakeholders?

Answering this question can be viewed as an extended problem explication. In other words, researchers will continue to explicate the problem further, but they will
do so using the proposed solution outline as a pair of glasses for guiding their examination of the problem. Thus, the question is to be answered by descriptive knowledge that specifies requirements on the artefact.
A requirement is a property of an artefact that is deemed as desirable by stakeholders
in a practice and that is to be used for guiding the design and development of the artefact. As further discussed below, a requirement can concern the functions,

structure, or environment of an artefact as well as the effects of using the artefact.

Requirements – Definition



The activity Define Requirements can be structured and visualised as in Fig. 6.1. The input is an explicated problem provided by the previous activity. The output is an artefact outline and a set of requirements. The resources used by the activity consist of knowledge in the research literature and other written sources, as well as assertions from stakeholders. The controls are primarily research strategies and methods but may also include practice-based approaches to requirements elicitation
and analysis.

In this activity, the explicated problem is transformed into a set of requirements to be used by the designer when designing and developing the artefact. If the problem has been further analysed by identifying a set of root causes, these can provide a starting point for defining the requirements, i.e. for each root cause, one or
several requirements can be defined. The requirements can then be traced back to the root causes upon which they are based.

Artefacts as Solutions to Problems in Practices

- Reactions to Problems
- Extreme Case 1: Accept the problem as a fact of life (stoic attitude) –
  - Example: Cancer
- Extreme Case 2: Abandon the practice
  - Example: Bloodletting, which was an established practice in medicine for centuries but ceased when evidence mounted regarding its adverse health effects
- Common - Try to find some, often partial, solution to it.

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When facing a practical problem, people may react to it in different ways. One option is to adopt a stoic attitude and just accept the problem as a fact of life without
trying to do anything about it. The other extreme would be to view the problem as being so serious that the entire practice should be abandoned, or at least part of it. An example is bloodletting, which was an established practice in medicine for centuries but ceased when evidence mounted regarding its adverse health effects. However, the most common reaction to a practical problem is to try to find some, often partial, solution to it.

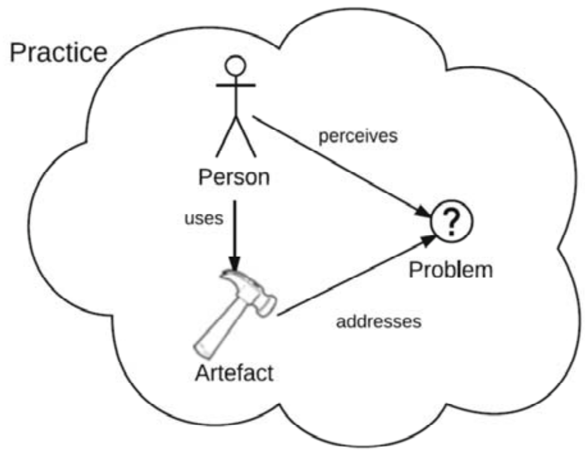
Artifact - Definition

- **Artefact (Definition)** - An object made by humans with the intention that it be used to address a practical problem.

- **Type of Artifacts**
  - Physical Objects – Examples: hammers, cars, and hip joint
  - Plans (drawings or blueprints) – Example: architect’s plan for a building
  - Methods, Guidelines, Algorithms, Processes - Example: A method for designing databases, logic programs, software architectures, information models

In many cases, practical problems can be solved by means of artefacts. An artefact is defined here as an object made by humans with the intention that it be used to address a practical problem. Some artefacts are physical objects, such as hammers, cars, and hip replacements. Other artefacts take the form of drawings or blueprints, such as an architect’s plan for a building. Methods and guidelines can also be artefacts, for example, a method for designing databases. Common to all these artefacts is that they support people when they encounter problems in some practice.

Artifact – Definition



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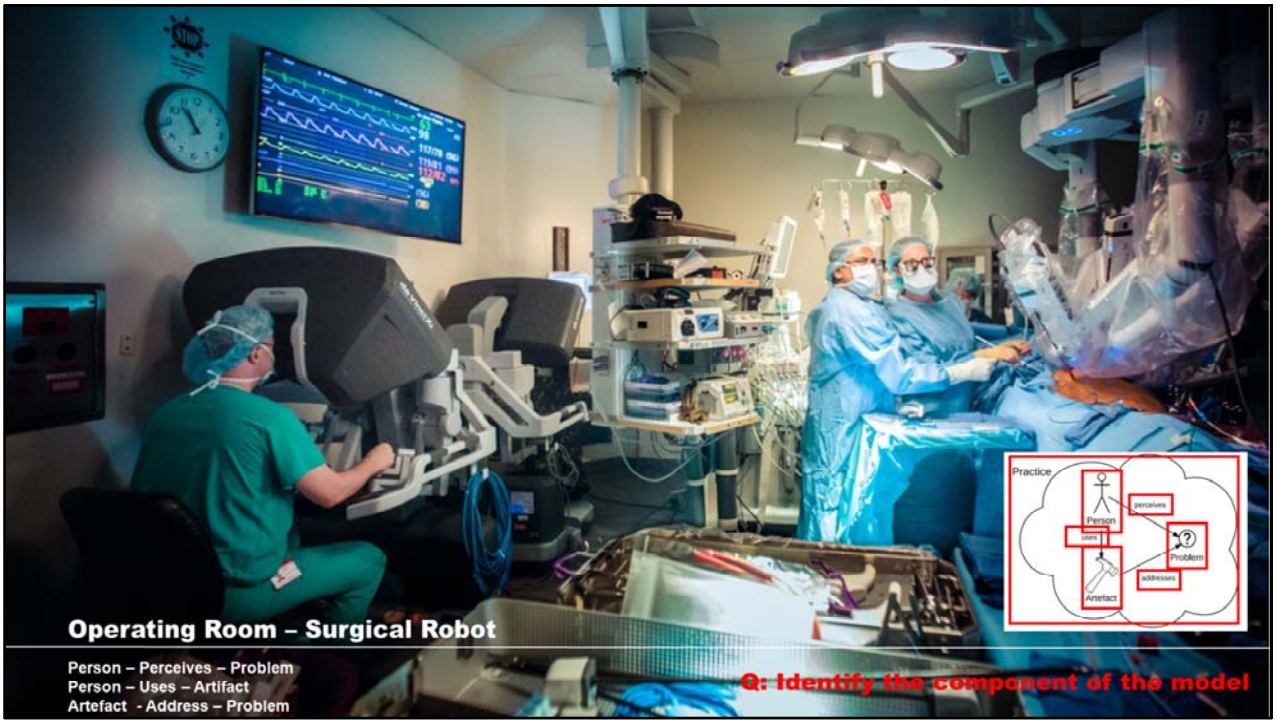
The relationships between people, practices, problems, and artefacts are
summarised in Fig. 1.1. People engage in practices in which they may perceive
problems that can be addressed by means of artefacts. Thus, artefacts do not exist
in
isolation but are always embedded in a larger context.


Operating Room – Surgical Robot
Person – Perceives – Problem
Person – Uses – Artifact
Artefact - Address – Problem
Q: Identify the component of the model
Practice
Person
perceives
uses
Problem
addresses
Artefact


Operating Room – Surgical Robot
Person – Perceives – Problem
Person – Uses – Artifact
Artefact - Address – Problem
Practice
Person
perceives
uses
Problem
addresses
Artefact
Q: What is the practice


Operating Room – Surgical Robot
Person – Perceives – Problem
Person – Uses – Artifact
Artefact - Address – Problem
Q: What is the practice
Practice
Person
perceives
uses
Problem
addresses
Artefact


Practice
perceives
Person
uses
Problem
addresses
Artefact
Operating Room – Surgical Robot
Person – Perceives – Problem
Person – Uses – Artifact
Artefact - Address – Problem
Q: What is the problem


Operating Room – Surgical Robot
Person – Perceives – Problem
Person – Uses – Artifact
Artefact - Address – Problem
Q: What is the problem
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uses
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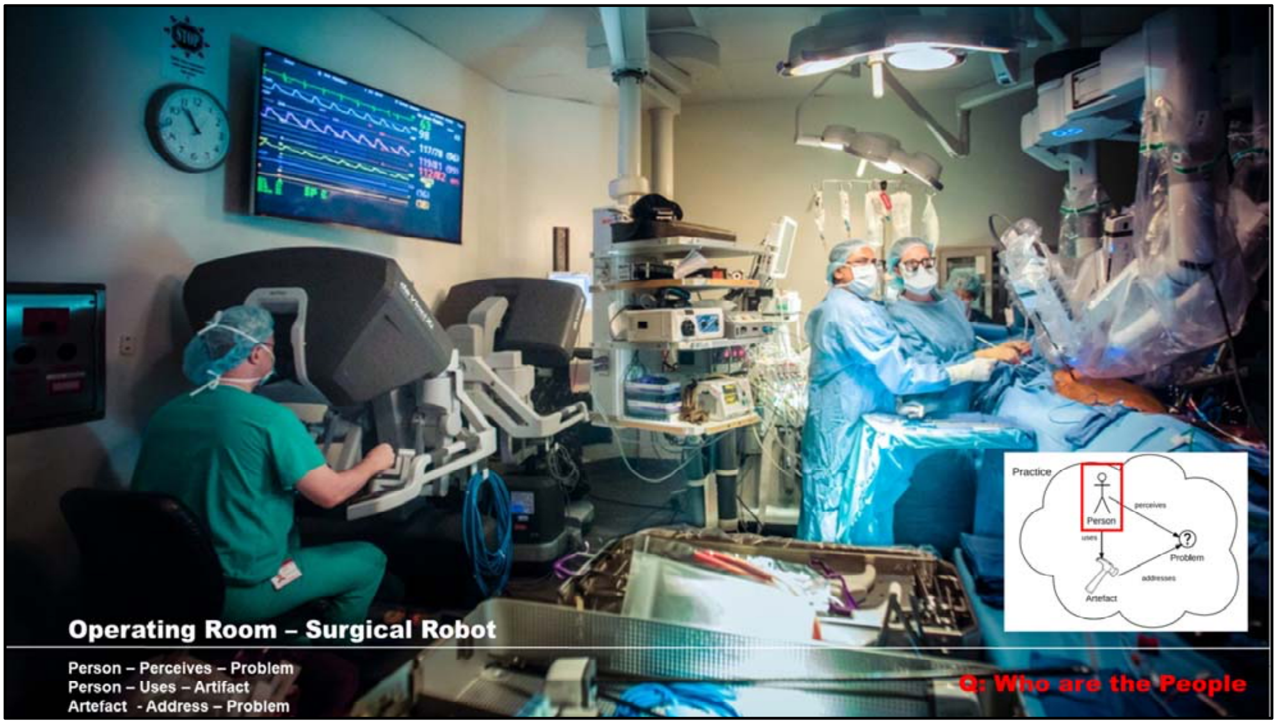
addresses
Artefact


Operating Room – Surgical Robot
Person – Perceives – Problem
Person – Uses – Artifact
Artefact - Address – Problem
Q: Who are the People
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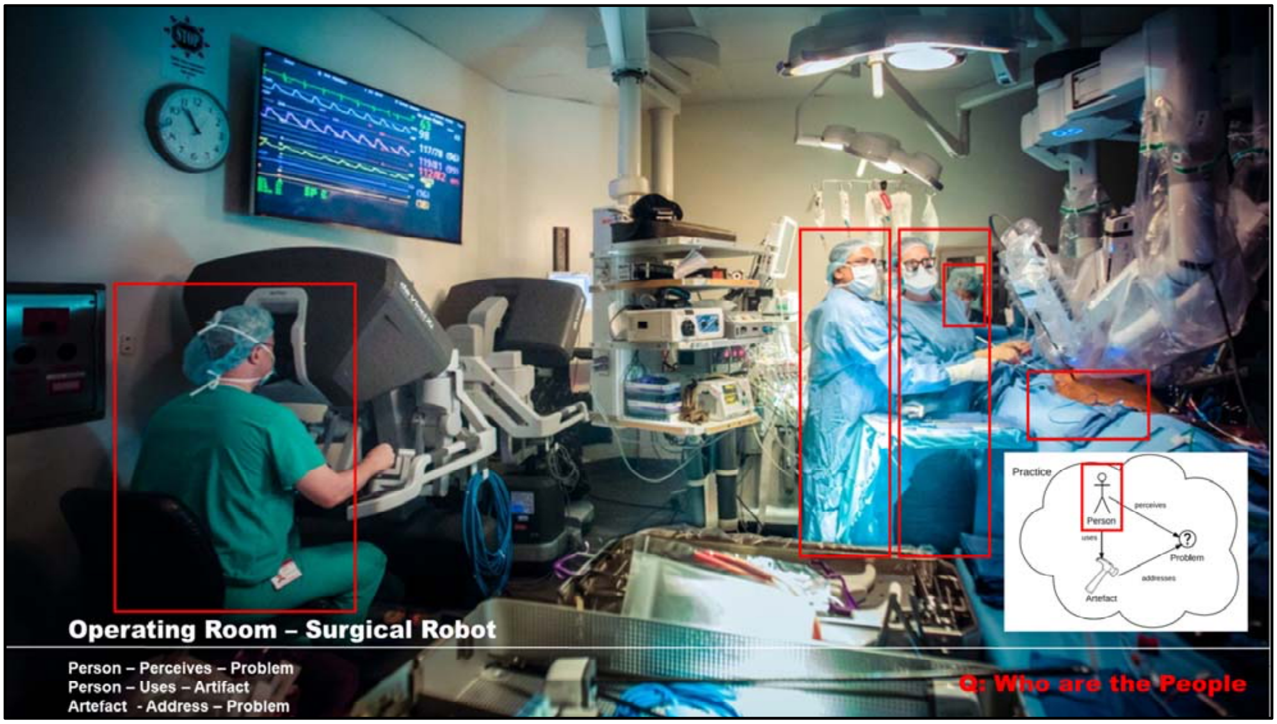
addresses
Artefact


Operating Room – Surgical Robot
Person – Perceives – Problem
Person – Uses – Artifact
Artefact - Address – Problem
Q: Who are the People
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addresses
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Operating Room – Surgical Robot
Person – Perceives – Problem
Person – Uses – Artifact
Artefact - Address – Problem
Q: What is the Artifacts
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perceives
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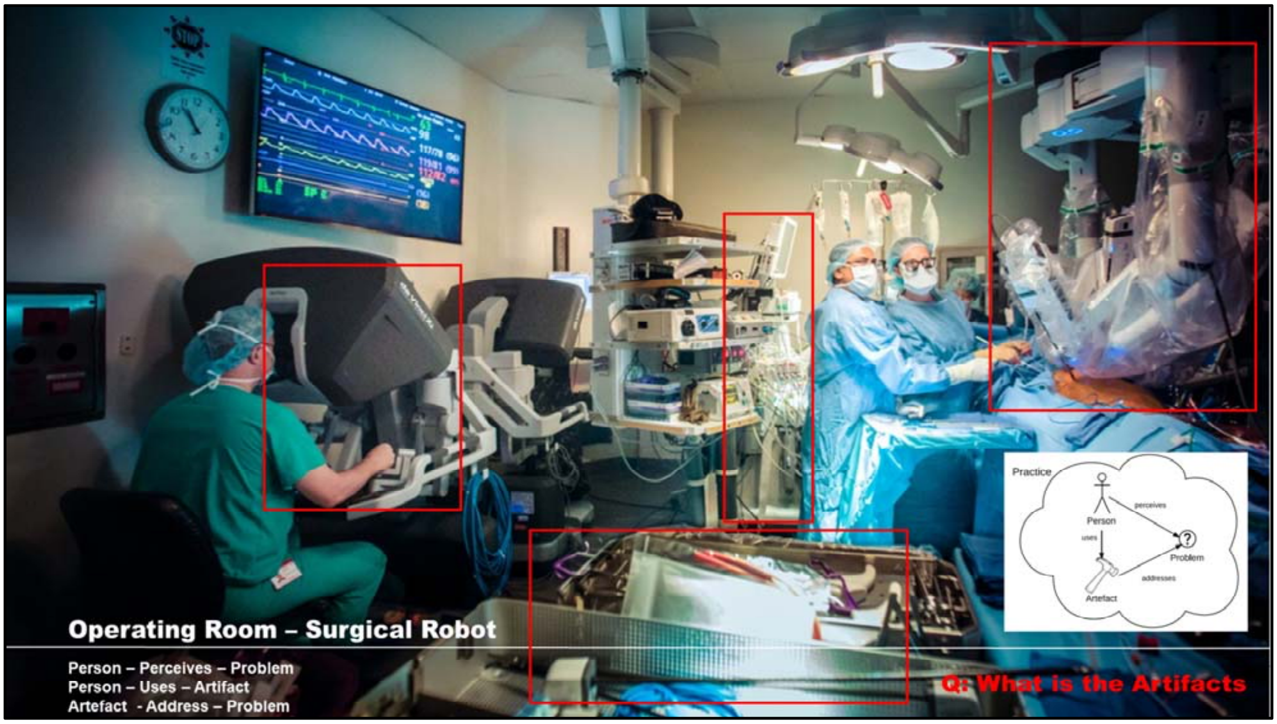
addresses
Artefact


Operating Room – Surgical Robot
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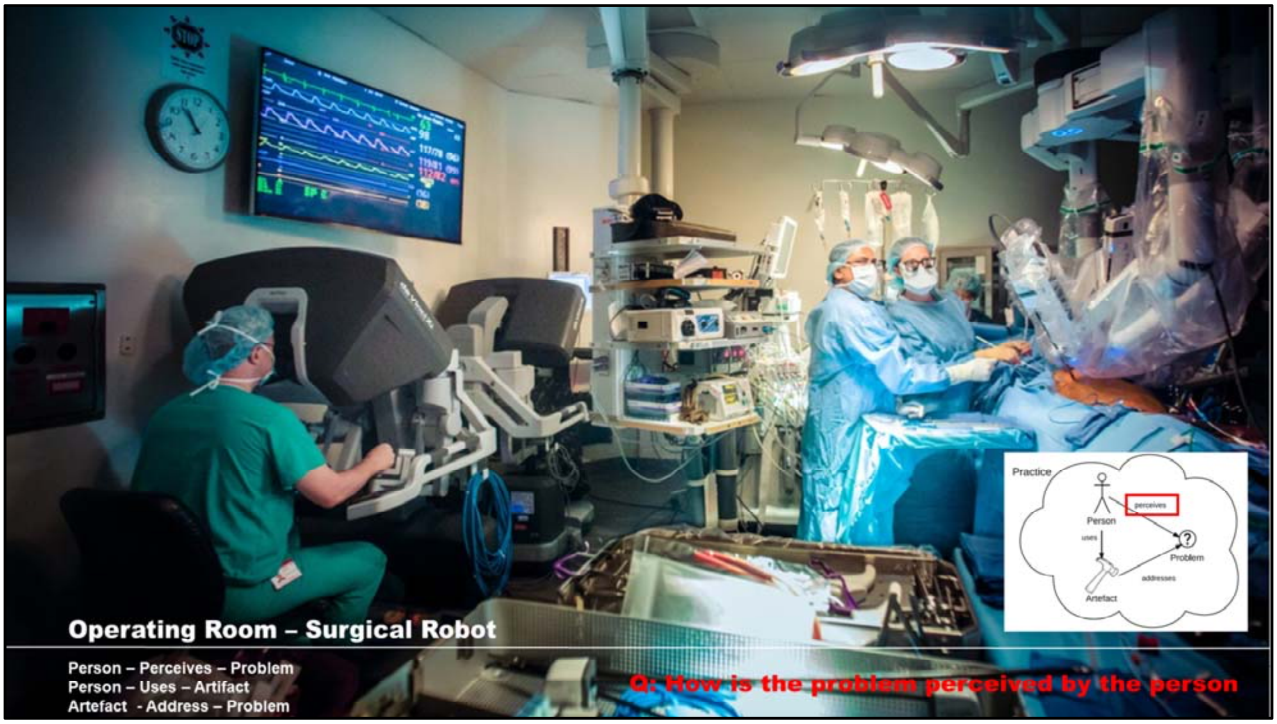
Operating Room – Surgical Robot
Person – Perceives – Problem
Person – Uses – Artifact
Artefact - Address – Problem
Q: How is the problem perceived by the person
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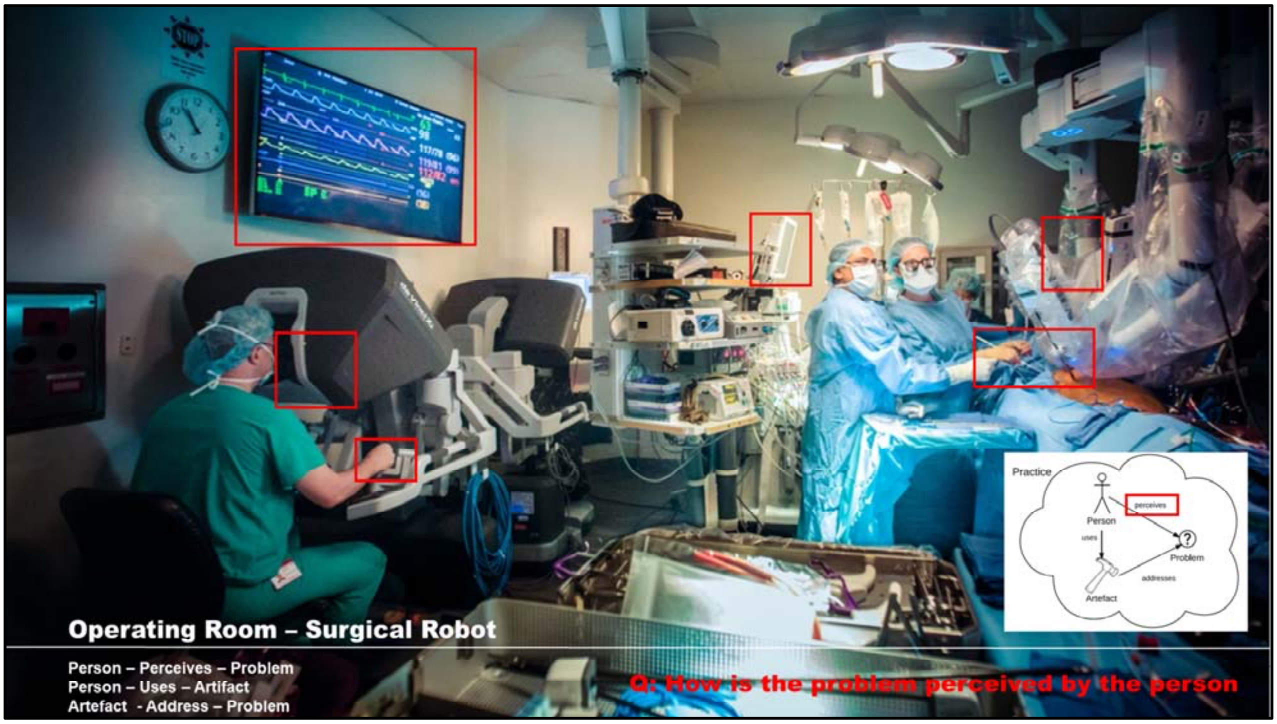
uses
Problem
addresses
Artefact



Operating Room – Surgical Robot
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Person – Uses – Artifact
Artefact - Address – Problem
Q: How is the problem perceived by the person
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Operating Room – Surgical Robot
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Person – Uses – Artifact
Artefact - Address – Problem
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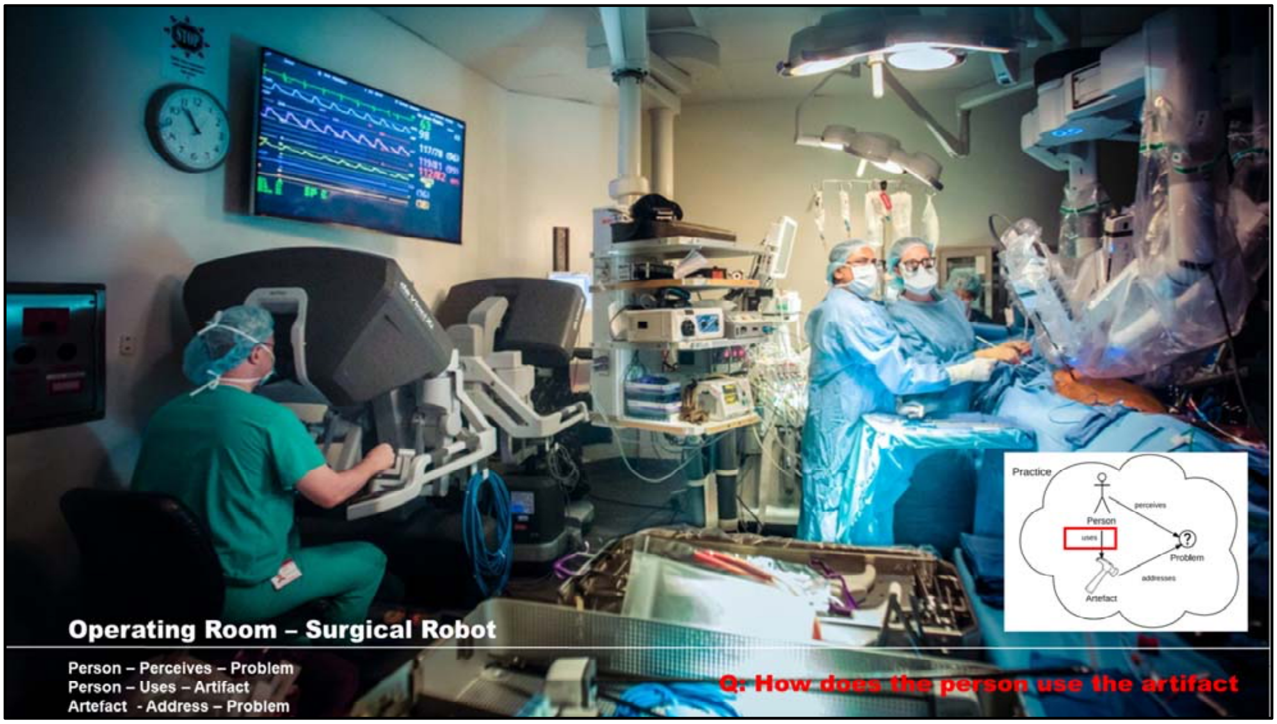
Artefact


Operating Room – Surgical Robot
Person – Perceives – Problem
Person – Uses – Artifact
Artefact - Address – Problem
Q: How does the person use the artifact
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uses
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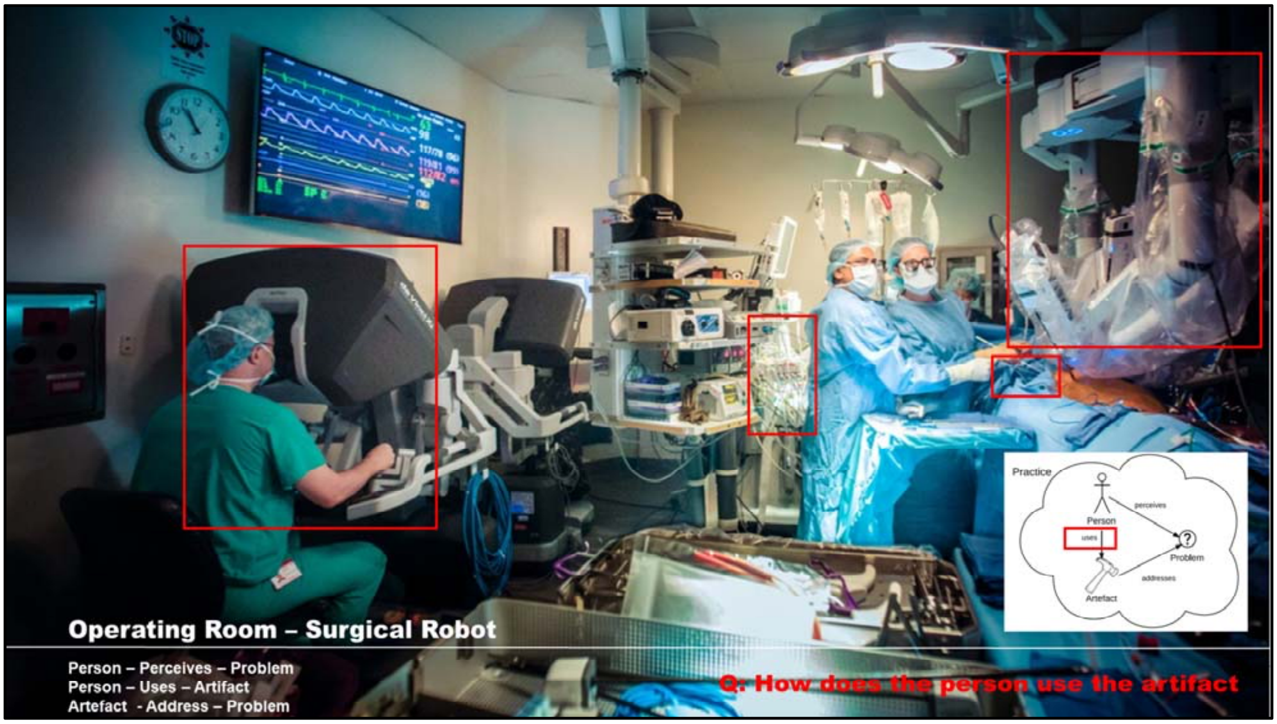
Problem
addresses
Artefact



Practice
perceives
Person
uses
?
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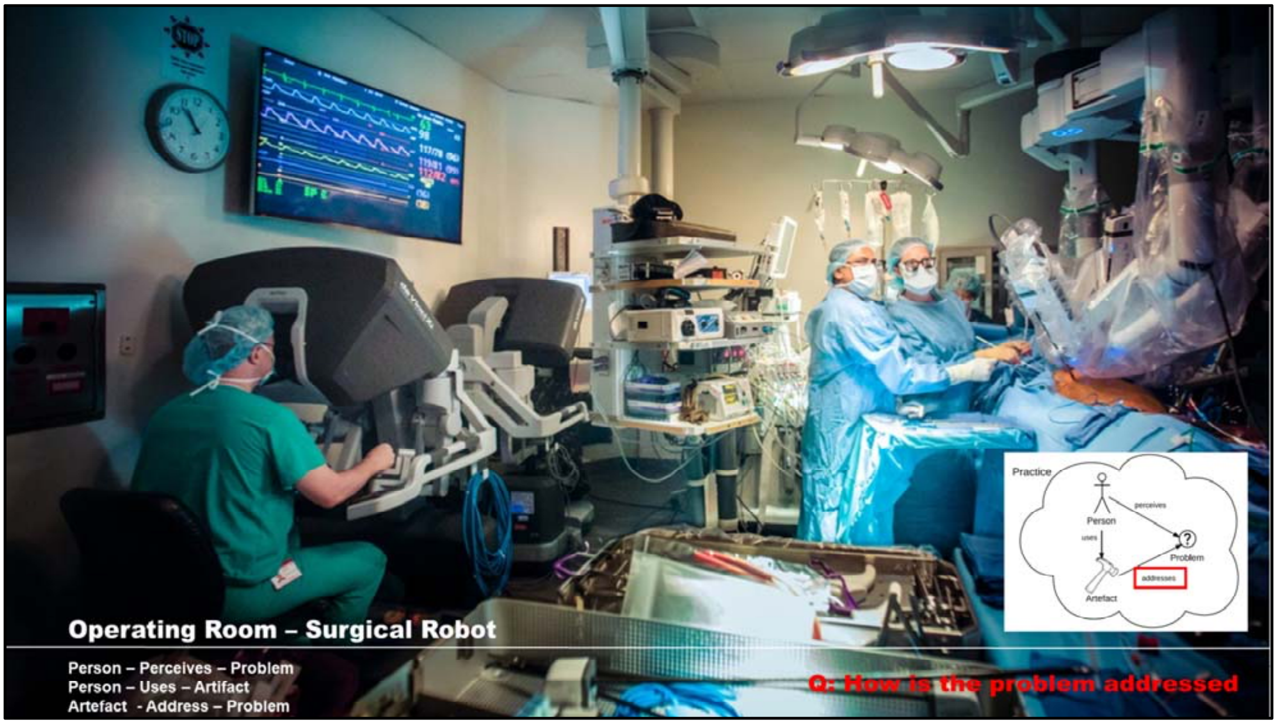
addresses
Artefact
Operating Room – Surgical Robot
Person – Perceives – Problem
Person – Uses – Artifact
Artefact - Address – Problem
Q: How does the person use the artifact


Practice
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perceives
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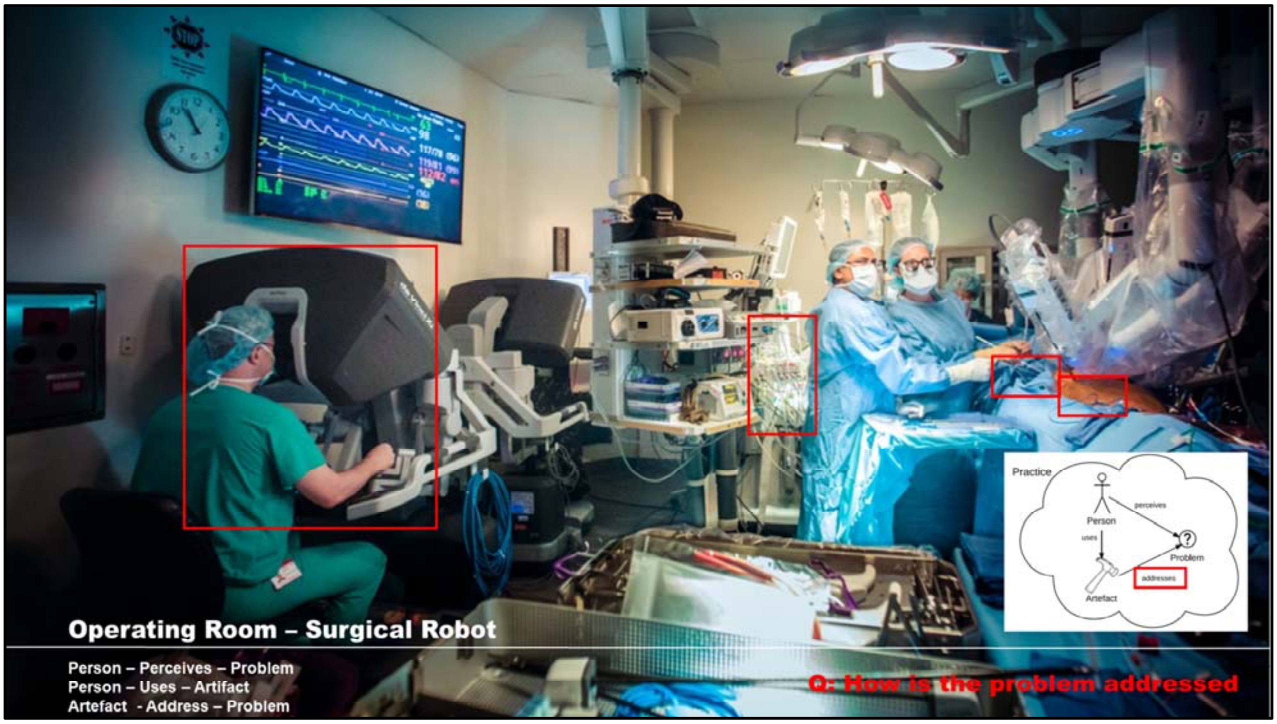
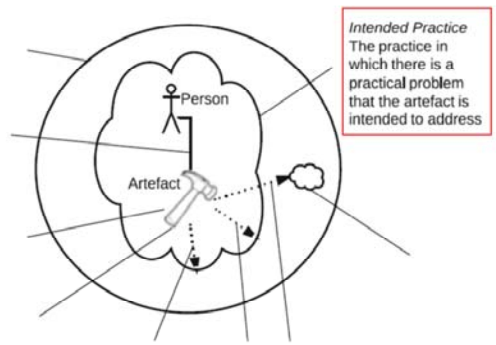
Problem
addresses
Artefact
Operating Room – Surgical Robot
Person – Perceives – Problem
Person – Uses – Artifact
Artefact - Address – Problem
Q: How is the problem addressed



Practice
Person
perceives
uses
Problem
addresses
Artefact
Operating Room – Surgical Robot
Person – Perceives – Problem
Person – Uses – Artifact
Artefact - Address – Problem
Q: How is the problem addressed

Artifact - Context and Anatomy

- **Intended Practice** – Intended practice is practice that contains the practical problem that the artefact addresses.



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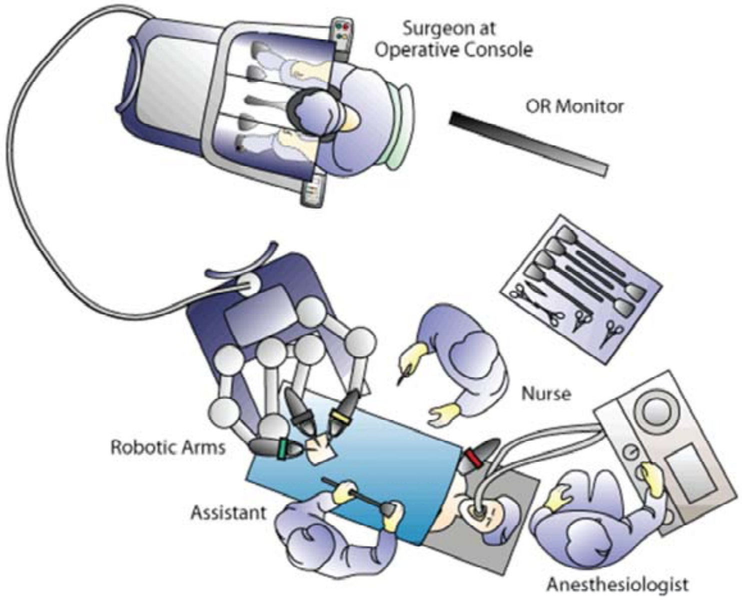
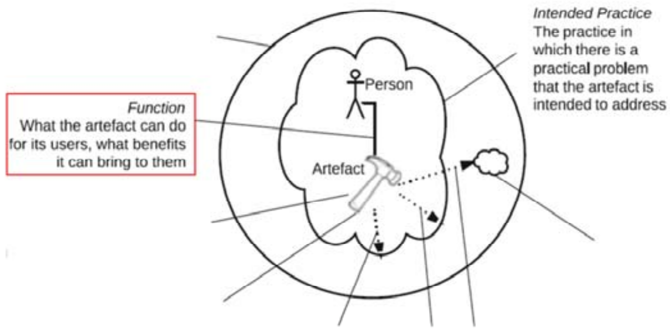
Every artefact has an inside, an outside, and an interface between the inside and outside. More precisely, every artefact has an inner structure that can produce certain behaviours, and these can offer functions for people in the intended practice of the artefact. The intended practice is defined here as the practice that contains the practical problem that the artefact addresses..



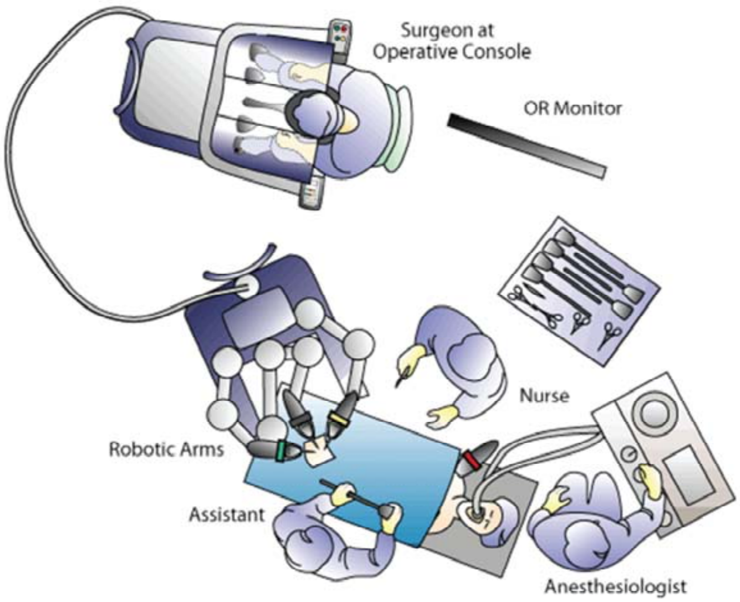
- **Intended Practice** – Intended practice is practice that contains the practical problem that the artefact addresses.
- **Robotics Surgery**

Artifact - Context and Anatomy

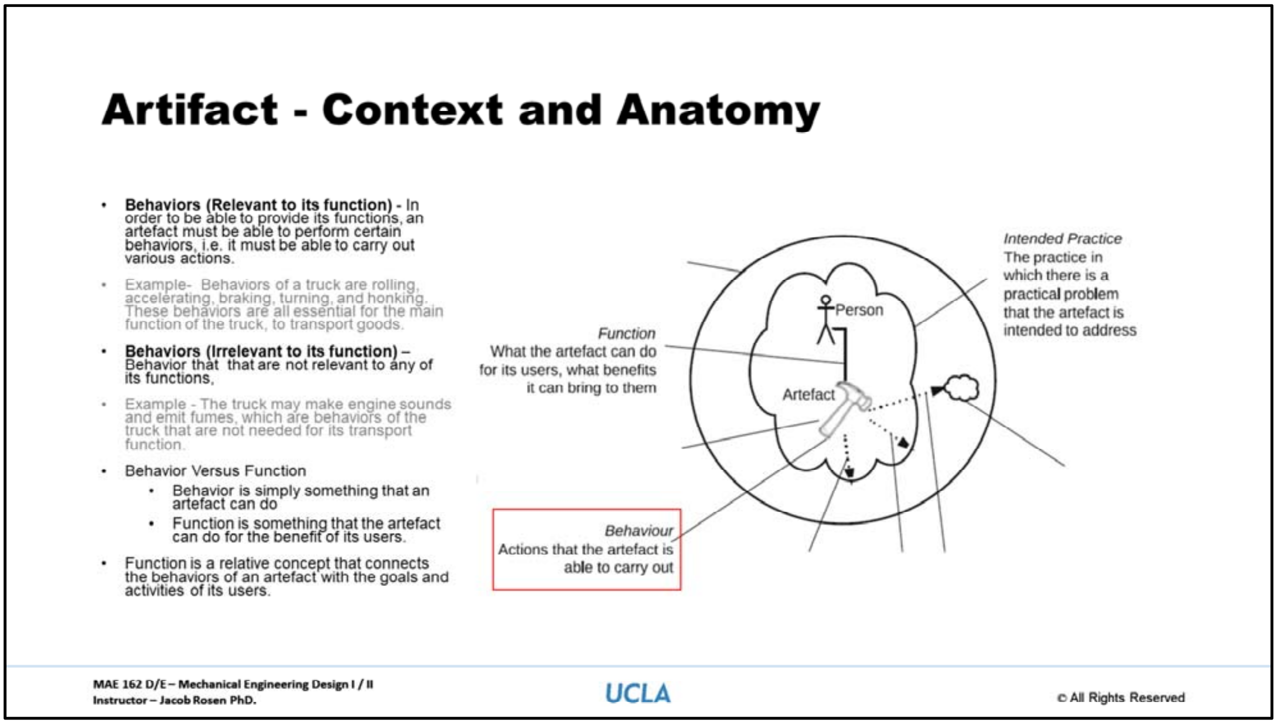
- **Functions**
  - **The artefact has been created to offer its functions.**
  - what it can **do** for its users,
  - what **benefits** it can bring to users in their practice
  - what **role** it can play for users
  - how it can **support** users in their activities.
- Examples
  - A function of a clock is to tell the time
  - A function of a lawn mower is to cut grass,
  - A function of a truck is to transport goods.



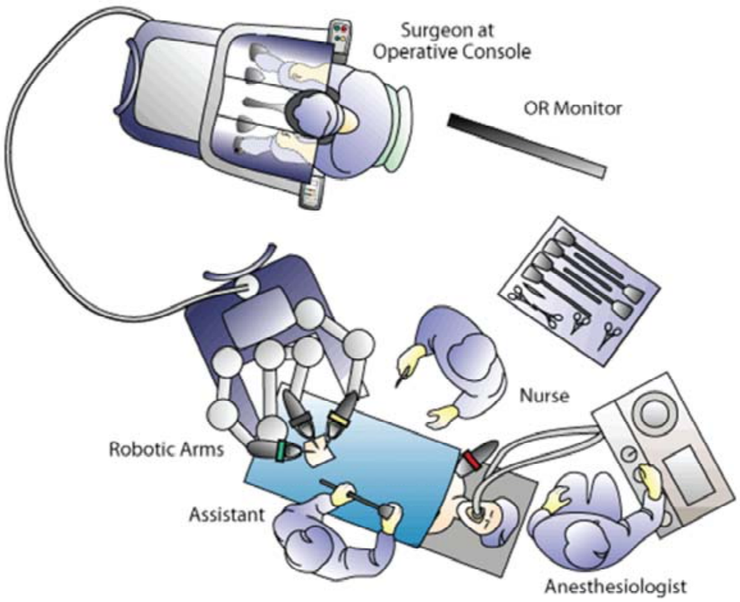
The functions of an artefact are what it can do for its users, what benefits it can bring to them in their practice, what role it can play for them, and how it can support
them in their activities. For example, a function of a clock is to tell the time, a function of a lawn mower is to cut grass, and a function of a truck is to transport goods. The functions of an artefact can be seen as its raison d’eˆtre—the artefact has
been created to offer its functions.



- Functions
  - **The artefact has been created to offer its functions.**
  - what it can **do** for its users,
  - what **benefits** it can bring to users in their practice
  - what **role** it can play for users
  - how it can **support** users in their activities.
- **Do / Role**
  - Perform Robotics Surgery
- **Benefits**
  - High dexterity
  - Superior Vision
  - Quick Recovery
  - Minimal scars
  - Low risk of infection
- **Support**
  - Reduce the surgeon's Cognitive load



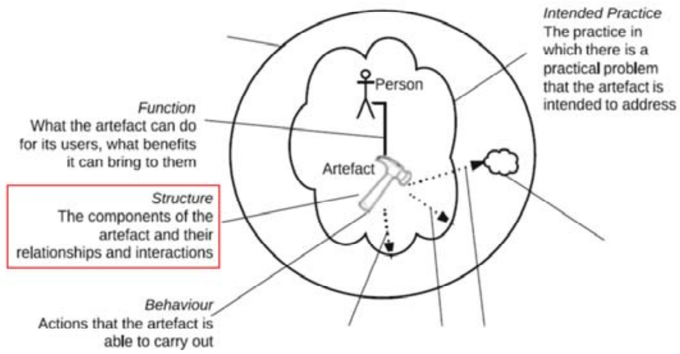
In order to be able to provide its functions, an artefact must be able to perform certain behaviors, i.e. it must be able to carry out various actions. For example, some of the behaviors of a truck are rolling, accelerating, braking, turning, and honking. These behaviors are all essential for the main function of the truck, to transport goods. However, an artefact may also exhibit behaviors that are not relevant to any of its functions, e.g. the truck may make engine sounds and emit fumes, which are behaviors of the truck that are not needed for its transport function. While a behavior is simply something that an artefact can do, a function is something that the artefact can do for the benefit of its users. In this sense, function is a relative concept that connects the behaviors of an artefact with the goals and activities of its users.



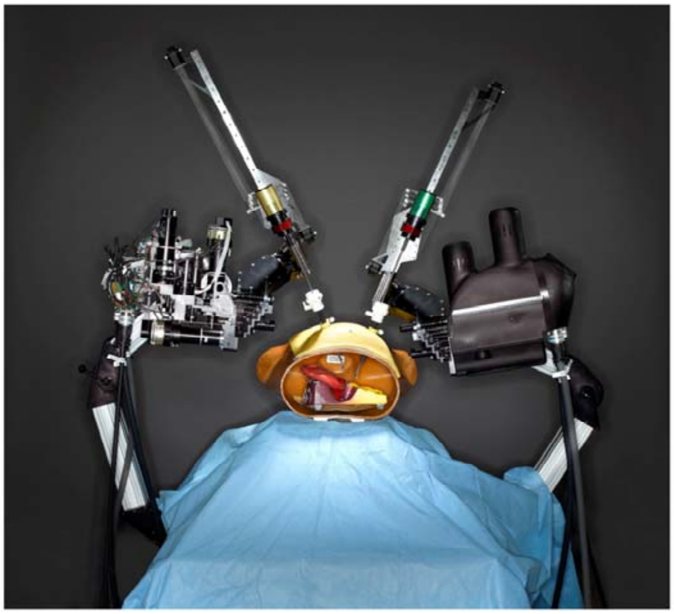
- **Behaviors (Relevant to its function) –**
  - Manipulate surgical tools and endoscope
- **Behaviors (Irrelevant to its function) –**
  - Surgical robotics tools may collide outside of the patient
  - Pose a risk to the patient due to dysfunction
  - Disrupt the communication and collaboration between the primary surgeon and the assistant

Artifact - Context and Anatomy

- **Structure (Inside of the Artifact)** - In order to produce its behaviors, the artefact has to be constructed and configured in a certain way. The structure of an artefact is about its inner workings, the components it consists of, how these are related, and how they interact with each other.
  - Example: Clock constructed from cogwheels springs, body, interface
  - Example: Truck made of a chassis, an engine, wheels,



In order to produce its behaviors, the artefact has to be constructed and configured in a certain way. The structure of an artefact is about its inner workings, the components it consists of, how these are related, and how they interact with each
other. Typically, an artefact is constructed from smaller parts that are assembled in such a way that they can interact with each other and produce the artefact's behavior. An example is a clock constructed from cogwheels, watch-hands, and other mechanical parts. Another example is a truck, which is made of a chassis, an engine, wheels, and other parts.



- **Structure (Inside of the Artifact)** - In order to produce its behaviors, the artefact has to be constructed and configured in a certain way. The structure of an artefact is about its inner workings, the components it consists of, how these are related, and how they interact with each other.

- **Surgical Robot**
  - Long Surgical Robotics tools
  - Remote center of rotation
  - Cable driven mechanism

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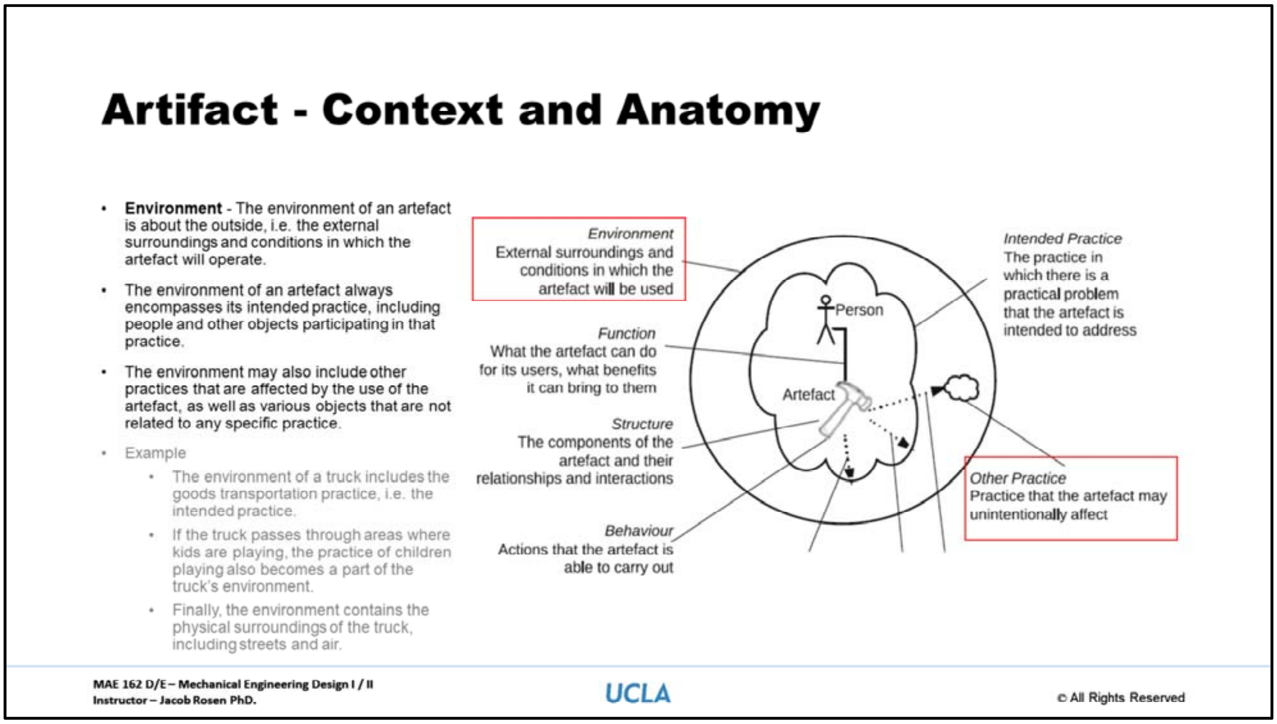
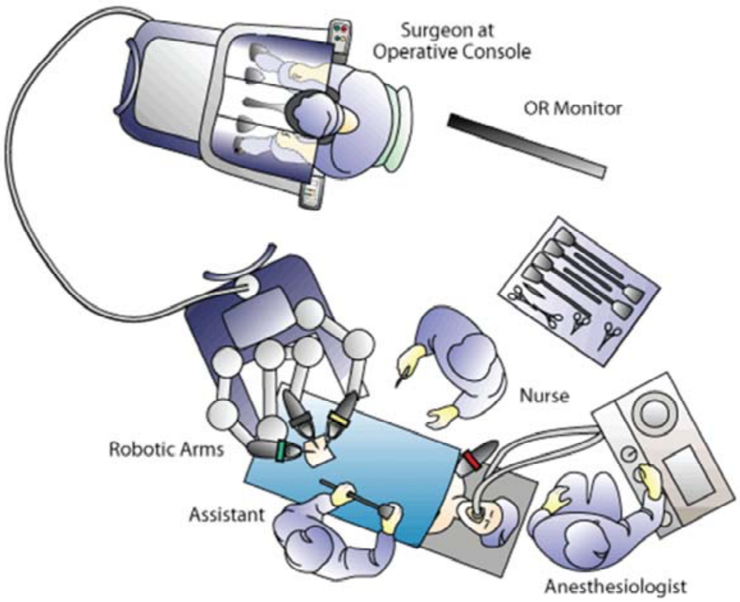
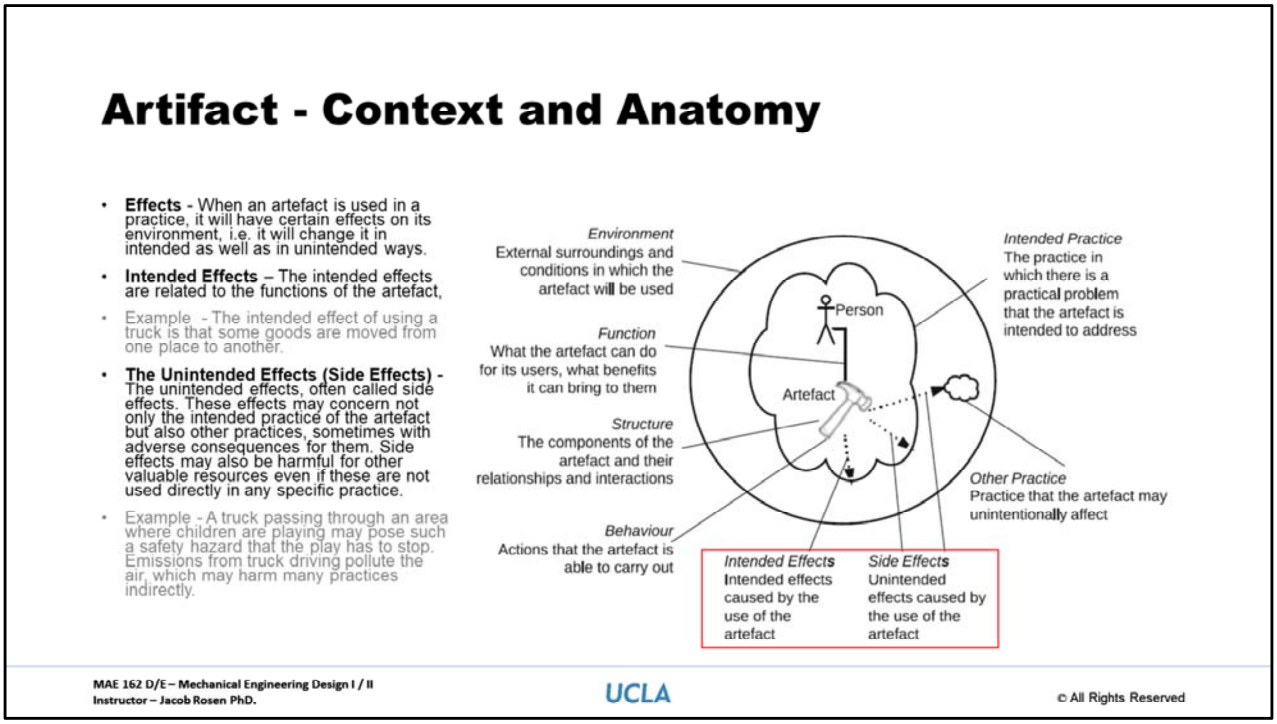


While the structure of an artefact is about its inside, its environment is about the outside, i.e. the external surroundings and conditions in which the artefact will operate. The environment of an artefact always encompasses its intended practice, including people and other objects participating in that practice. The environment may also include other practices that are affected by the use of the artefact, as well as various objects that are not related to any specific practice. As an example, the environment of a truck includes the goods transportation practice, i.e. the intended practice. If the truck passes through areas where kids are playing, the practice of children playing also becomes a part of the truck's environment. Finally, the environment contains the physical surroundings of the truck, including streets and air.

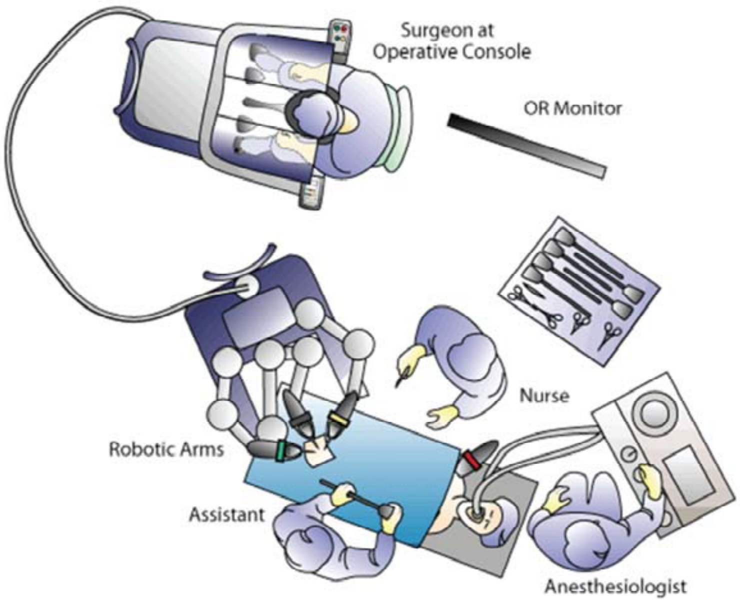


- **Environment** - The environment of an artefact is about the outside, i.e. the external surroundings and conditions in which the artefact will operate.
- The environment of an artefact always encompasses its intended practice, including people and other objects participating in that practice.
- The environment may also include other practices that are affected by the use of the artefact, as well as various objects that are not related to any specific practice.

- **Environment**
  - Type 1 – Operating Room
  - Type 2 – Patient Body
- **People**
  - Surgeon
  - Assistant
  - Nurse
  - Anesthesiologist
- **Nature of the environment**
  - Sterile / Non Sterile
- **Other practices**
  - Anesthesiologist



When an artefact is used in a practice, it will have certain effects on its environment, i.e. it will change it in intended as well as in unintended ways. The intended effects are related to the functions of the artefact, e.g. the intended effect of using a truck is that some goods are moved from one place to another. Using an artefact may also have unintended effects, often called side effects. These effects may concern not only the intended practice of the artefact but also other practices, sometimes with adverse consequences for them. For example, a truck passing through an area where children are playing may pose such a safety hazard that the play has to stop. Side effects may also be harmful for other valuable resources even if these are not used directly in any specific practice. Emissions from truck driving pollute the air, which may harm many practices indirectly.



- **Effects** - When an artefact is used in a practice, it will have certain effects on its environment, i.e. it will change it in intended as well as in unintended ways.

- **Intendent Effects** – Change the anatomy / physiology of the patent body
- **Intendent Effects**
  - Bleeding
  - Tissue damage

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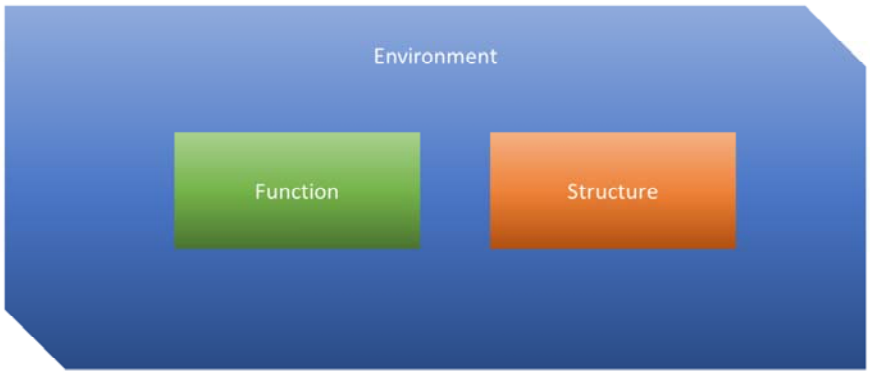
Requirements – Structure & Function



Requirements – Structure & Function Common Design Principle

- **Design Principles -** A common guiding principle in the design of an artefact is to
  - **Hide Structure** - Hide its structure from its future users. Users should not need to care about the internal structure of the artefact
  - **Explore Function** - Focus on its functions how it can serve them. Ideally, the users should not even be aware of the structure.

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A common guiding principle in the design of an artefact is to hide its structure from its future users and instead to focus on its functions. Users should not need to care about the internal structure of the artefact but only about its functions, i.e. how
it can serve them. Ideally, the users should not even be aware of the structure. An example is a clock, which someone can use without knowing whether it is constructed using mechanical parts or electronic components. In the history of IT, the idea of hiding the internals of an artefact has been applied repeatedly with labels
such as encapsulation, object orientation, information hiding, and service-oriented architectures.

Requirements – Structure & Function
Common Design Principle

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Requirements – Structure & Function
Common Design Principle

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Requirements – Structure & Function Specific Occupation

- **Function & Structure in Specific Practice** - The distinction between structure, function, and environment is sometimes reflected in the professional roles of designers.
  - Example 1 - Construction Industry,
    - Engineer - a construction engineer will focus on the internal structure of buildings, including the selection of building materials, the layout of plumbing, the strength calculations, etc.
    - Architect – Architect will focus on the environment and functions of buildings in order to cater for external constraints as well as for the needs and requirements of the users.
  - Example 2 - IT and information systems industry,
    - Enterprise architects –
      - Business requirements
      - Legal issues,
      - Cultural factors
      - Environmental Aspects
    - Programmers and Software Engineers
      - construction of the software within the systems to be built.

The distinction between structure, function, and environment is sometimes reflected in the professional roles of designers. For example, in the construction industry, a construction engineer will focus on the internal structure of buildings, including the selection of building materials, the layout of plumbing, the strength calculations, etc. An architect, on the other hand, will focus on the environment and functions of buildings in order to cater for external constraints as well as for the needs and requirements of the users. Similarly, in the IT and information systems industry, enterprise architects address business requirements as well as legal, cultural, and other environmental factors, while programmers and software engineers
focus on the construction of the software within the systems to be built.

Types of Requirements – Functional Requirements

- **Functional Requirements** - When designing an artefact, a designer often starts by creating a specification that defines its functional requirements,
  - **Problem Related** - Depends on the problem to be addressed
  - **User Related Needs & Wants** - Functions that the artefact should offer to the users along with their needs and wants
  - **No reference to its structure** - The structure can be developed later on when the designer has a more complete understanding of the requirements
  - **Situation Related** - Very specific to the situation at hand.
    - Examples - Electronic health record system
      - Technical: Provide storage of imaging scanning (X-rays CT MRI)
      - User (Physician): Enable doctors to enter information about investigations and treatments,
      - Users (Patients): Allow patients to enter information on their self medication.

When designing an artefact, a designer often starts by creating a specification that defines its functional requirements, i.e. the functions that the artefact should offer. For example, two requirements for a watch could be that it should be usable as a stopwatch and as an alarm clock. Typically, requirements are gathered from and validated by people within the intended practice. The requirements can be expressed as a list of functions of the artefact, with no reference to its structure. Instead, the structure can be developed later on when the designer has a more complete understanding of the requirements. However, in practice, function and structure are almost always elaborated in an iterative way. A designer can also specify non-functional requirements on an artefact, i.e. requirements that do not address functionality but instead general qualities such as security, usability, maintainability, and scalability.

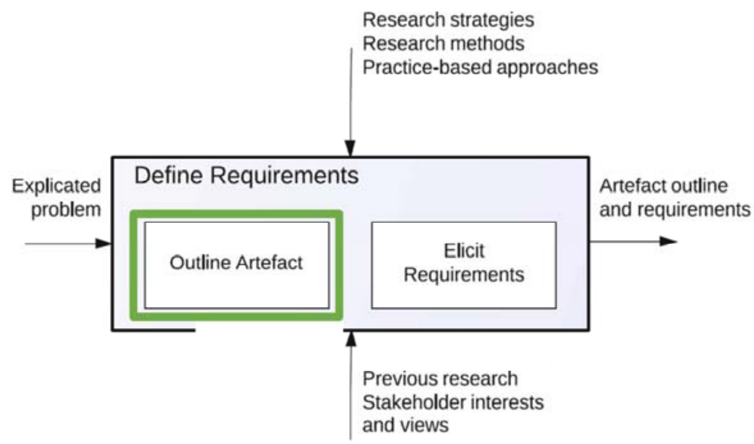
Functional requirements refer to the functions of the artefact and depend on the problem to be addressed as well as the needs and wants of the stakeholders. Some examples of functional requirements for an electronic health record system could be

to provide storage of X-rays, to enable doctors to enter information about investigations and treatments, and to allow patients to enter information on their selfmedication. As can be seen from this example, functional requirements are often very specific to the situation at hand. In contrast, structural requirements pertaining to structure and environmental requirements pertaining to the environment are typically more generic. Examples of structural requirements for the health record system could be that it should have a coherent and modular design. Examples of environmental requirements could be that the system should be available on different platforms and be easy to adapt to changes. Non-functional requirements are those requirements that are not functional and encompass both structural requirements and environmental requirements. In addition to the functional and non-functional requirements, it is also possible to formulate requirements, or rather goals, on the effects of using an artefact, for example, that the use of a new IT system should increase profits by 5% or make the corporate culture less hierarchic.

Types of Requirements – Non Functional Requirements

- **None Functional Requirements** - Non-functional requirements on an artefact, i.e. requirements that do not address functionality but instead general qualities
  - Examples: security, usability, maintainability, and scalability.
- **Structural Requirements** – Structure of the artifact
  - Examples - Electronic health record system
    - Coherent and Modular design
- **Environmental Requirements** – Environment surrounding the artifact
  - Examples - Electronic health record system
    - Be available on different platforms
    - Be easy to adapt to changes
- **Usage Requirements - Goals on the effects of using an artefact**
  - Example - the use of a new IT system should
    - increase profits by 5% or
    - make the corporate culture less hierarchic.

Requirements – Definition



The sub-activity Outline Artefact starts by choosing which artefact type should be designed in order to solve the problem, i.e. choosing whether the solution should be
a construct, a model, a method, or an instantiation. This choice is sometimes simple due to the characteristics of the explicated problem. In other cases, it can be more difficult to choose the artefact type to be designed. For example, if IT systems need to be integrated to make a business process more efficient, a solution can be a method for integrating IT systems, a model of an integration architecture, or an instantiation in the form of an integration tool. When the artefact type has been chosen, the artefact is to be described at an overview level.

Artifacts Type 1
Constructs, Models, Methods, and Instantiations

- **Constructs** - Constructs are terms, notations, definitions, and concepts that are needed for formulating problems and their possible solutions. Constructs do not make any statements about the world, but they make it possible to speak about it, so it can be understood and changed. Thus, constructs are definitional knowledge. They are the smallest conceptual atoms with which to understand and communicate about various phenomena.
  - Form the vocabulary of a domain
  - Describe problems within the domain and specify their solutions
- **Models** - Models are representations of possible solutions to practical problems, so a model can be used for supporting the construction of other artefacts. For example, a drawing can be used for building a house, and a database model can be used for developing a database system. As models prescribe the structure of other artefacts, they express prescriptive knowledge. A model is built up from constructs that ar
  - Combination of constructs
  - Represent situations as problem and solution statements
  - Concern of models is utility e related to each other.

Constructs are terms, notations, definitions, and concepts that are needed for formulating problems and their possible solutions. Constructs do not make any statements about the world, but they make it possible to speak about it, so it can be understood and changed. Thus, constructs are definitional knowledge. They are the smallest conceptual atoms with which to understand and communicate about various phenomena. Some examples are the concepts of class in the Unified Modeling Language (UML), method in Java, functional dependency in relational database theory, and affordance in human-computer interaction.

Models are representations of possible solutions to practical problems, so a model can be used for supporting the construction of other artefacts. For example, a drawing can be used for building a house, and a database model can be used for developing a database system. As models prescribe the structure of other artefacts, they express prescriptive knowledge. A model is built up from constructs that are related to each other.

Methods express prescriptive knowledge by defining guidelines and processes for how to solve problems and achieve goals. In particular, they can prescribe how to create artefacts. Methods can be highly formalised like algorithms, but they can also be informal such as rules of thumb or best practices. Some examples are methods for database design, change management initiatives, or web service development.

Artifacts Type 1
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  - Set of steps used to perform a task and/or solve a problem
  - Based on a set of underlying constructs and models of the solution space
  - Methodological tools are used by natural scientists
  - e.g. an algorithm or manual
- **Instantiations** - Instantiations are working systems that can be used in a practice. Instantiations can always embed knowledge, e.g. a database can embed a database model. Some examples of instantiations are a Java program realising a search algorithm, a database for electronic medical records, or a new planet in the computer game Entropia.
  - Realization of artifacts in its environment
  - Demonstrate the feasibility and effectiveness of the models and methods they contain
  - Their study can lead to significant advancements in design and natural science
  - e.g. software, hardware

Artifacts Type 2
A Function-Oriented Artefact Classification

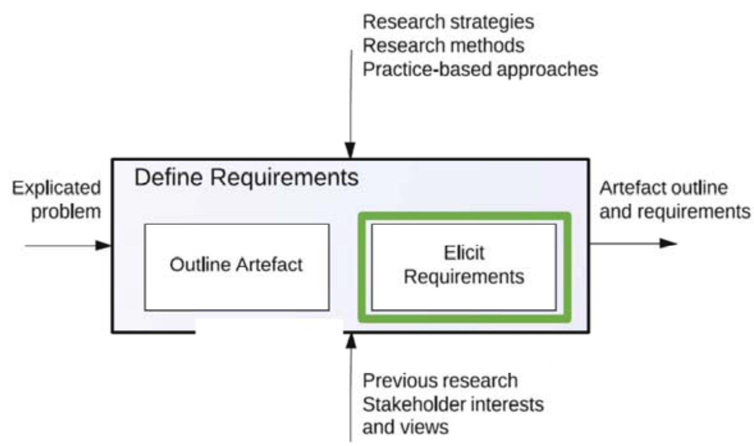
Archetype	Function	Examples
Processor	To automate	Transaction processing systems, embedded control systems
Tool	To augment	Computer-aided design systems, word processors, spreadsheets
Medium	To mediate	Email, blogs, social software
Information source	To inform	Information systems
Game	To entertain	Computer games, edutainment
Piece of art	To create art	Computer art
Pet	To accompany	Digital pets, virtual and robotic

Another way of classifying artefacts is to focus on their function. Iivari (2007) proposes the classification of IT applications (instantiations) into seven archetypes based on their function, i.e. the roles they can play for their users, as shown in Table 2.1.
As the archetypes are ideal types, a single IT application may be classified under two or more archetypes. For example, an email system is primarily meant to mediate, but someone may also use it as a personal storage of information, thereby employing it as an information source.

Artifacts Type 3
A Pragmatic Artefact Classification

- **System Design** - A structure or behavior-related description of a system, typically using text and some formal language
- **Method** - A definition of activities to create or interact with a system
- **Language/Notation** - A (formalized) system to formulate statements about some domain
- **Algorithm** - An executable description of system behavior
- **Guideline** - A suggestion regarding behavior in a particular situation
- **Requirements** - A statement about required behavior and functions of a system
- **Pattern** - A definition of reusable design elements with their benefits and application context
- **Metric** - A mathematical model able to measure aspects of systems or methods

Requirements – Definition



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Elicit Requirements – Activities & Methods

Activities	Methods
Clarifying Objectivities	Objective Tree Method
Establishing Functions	Function Analysis Method
Setting Requirements	Performance Specification Method
Determining Characteristics	Quality Function Deployment Methods

Objective Tree Method

Clarifying Objectives

Clarifying Objectivities – Introduction

- **Aim** - The aim of the objectives tree method is to clarify design objectives and sub objectives, and the relationships between them.
- **Initial Approach – A simply a 'problem' that needs a solution – Vague Need** - When a client, sponsor or company manager first approaches a designer with a product need, the client perhaps knows only the type of product that is wanted, and has little idea of the details, or of the variants that might be possible. Or the 'need' might be much vaguer still: simply a 'problem' that needs a solution.
- **Starting Point – Ill Defined Problem with Vague Requirements** - The starting point for design work is therefore very often an ill defined problem, or a rather vague requirement.
- **End Point - Objective Statement for Defining the End Goal** - It will be quite rare for a designer to be given a complete and clear statement of design objectives. Yet the designer must have some objectives to work towards. The outcome of designing is a proposal for some means to achieve a desired end. That 'end' is the set of objectives that the designed object should meet.
- **Clarify the Design Objectives May Change Over Time** - An important first step in designing therefore is to try to clarify the design objectives. In fact, it is very helpful at all stages of designing to have a clear idea of the objectives, even though those objectives may change as the design work progresses. The initial and interim objectives may change, expand or contract, or be completely altered as the problem becomes better understood and as solution ideas develop. So it is quite likely that both' ends' and 'means' will change during the design process.

When a client, sponsor or company manager first approaches a designer with a product need, it is unlikely that the 'need' will be expressed as clearly as in the previous chapter. The client perhaps knows only the type of product that is wanted, and has little idea of the details, or of the variants that might be possible. Or the 'need' might be much vaguer still: simply a 'problem' that needs a solution. The starting point for design work is therefore very often an ill-defined problem, or a rather vague requirement. It will be quite rare for a designer to be given a complete and clear statement of design objectives. Yet the designer must have some objectives to work towards. The outcome of designing is a proposal for some means to achieve a desired end. That 'end' is the set of objectives that the designed object should meet.

An important first step in designing therefore is to try to clarify the design objectives. In fact, it is very helpful at all stages of designing to have a clear idea of the objectives, even though those objectives may change as the design work progresses. The initial and interim objectives may change, expand or contract, or be completely altered as the problem becomes better understood and as solution ideas develop.

So it is quite likely that both' ends' and 'means' will change during the design process. But as an aid to controlling and managing the design process it is important to have, at all times, a statement of objectives which is as clear as possible. This statement should be in a form which is easily understood and which can be agreed by the client and the designer, or by the various members of the design team. (It is surprising how often members of the same team can have different objectives!)

The objectives tree method offers a clear and useful format for such a statement of objectives. It shows the objectives and the general means for achieving them which are under consideration. It shows in a diagrammatic form the ways in which different objectives are related to each other, and the hierarchical pattern of objectives and subobjectives. The procedure for arriving at an objectives tree helps to clarify the objectives and to reach agreement between clients, managers and members of the design team.

Clarifying Objectivities – Introduction

- **Clear and Agreed (Stakeholder/ Designer) Statement of Objectives** - As an aid to controlling and managing the design process it is important to have, at all times, a statement of objectives which is as clear as possible. This statement should be in a form which is easily understood and which can be agreed by the client and the designer, or by the various members of the design team. (It is surprising how often members of the same team can have different objectives!)
- **Objectives Tree Method** -
  - **Clear & Simple Format** - Offers a clear and useful format for a statement of objectives
  - **Objectives & Means** - Shows the objectives and the general means for achieving them
  - **Relationships Between Objectives (Hierarchy)** - Ways in which different objectives are related to each other and the hierarchical pattern of objectives and sub objectives.
  - **Agreement** - Reach agreement between clients, managers and members of the design team

Objective Tree Method – Procedure
Step 1 - Prepare a list of design objectives

- **Prepare a List of Design Objective** - Mixture of abstract and concrete aims that the design must try to satisfy or achieve.
  - Client requirements
  - User needs
  - Product purpose.
  - Example,
    - Set No. 1 - Safety,
    - Set No. 2 – Effectiveness
    - Set No. 3 – Reliability
    - Set No. 4 – Cost
    - Set No. 5 – Performance
    - Set No. 6 – Comfort
    - Set No. 7 – Eco – Friendly
    - Example: 'The product must be safe and reliable'.
- **Ask 'What is Meant by that Statement** - Try to specify what it means. Ask 'what is meant by that statement?'
  - Example: an objective for a machine tool that it must be 'safe', might be expanded to mean:
    1. Low risk of injury to operator.
    2. Low risk of operator mistakes.
    3. Low risk of damage to work piece or tool.
    4. Automatic cut-out on overload.
- Clarify the Objective by **Asking WH questions** - **'why?', 'how?'** and **'what?'**
  - Example
    - **'Why do we want to achieve this objective?'**
    - **'How can we achieve it?'**
    - 'What implicit objectives underlie the stated ones?'
    - 'What is the problem really about?'

MAE 162 D/E – Mechanical Engineering Design I / II
Instructor – Jacob Rosen PhD.

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The 'brief for a design problem is often very aptly called that- it is a very brief statement! Such brevity may be because the client is very uncertain about what is wanted, or it may be because he or she assumes that the designer perfectly understands what is wanted. Another alternative is that the client wishes to leave the designer with as much freedom as possible. This might sound like a distinct advantage to the designer, but can lead to great frustration when the client decides that the final design proposal is definitely not what was wanted! In any case, the designer will almost certainly need to develop the initial brief into a clear statement of design objectives.

The design objectives might also be called client requirements, user needs or product purpose. Whatever they are called, they are the mixture of abstract and concrete aims that the design must try to satisfy or achieve.

Some design objectives will be contained within the design brief; others must be obtained by questioning the client, or by discussion in the design team. Typically, initial statements of objectives will be brief and rather vague, such as 'The product must be safe and reliable'. To produce more precise objectives, you will need

to expand and to clarify such statements.
One way to begin to make vague statements more specific is, literally, to try to specify what it means. Ask 'what is meant by that statement?' For example, an objective for a machine tool that it must be 'safe', might be expanded to mean:

1. Low risk of injury to operator.
2. Low risk of operator mistakes.
3. Low risk of damage to workpiece or tool.
4. Automatic cut-out on overload.

This kind of list can be generated simply at random as you think about the objective, or in discussion within the design team. The client may also have to be asked to be more specific about objectives included in the design brief.
The types of questions that are useful in expanding and clarifying objectives are the simple ones of 'why?', 'how?' and 'what?' For instance, ask 'why do we want to achieve this objective?', 'how can we achieve it?' and 'what implicit objectives underlie the stated ones?' or 'what is the problem really about?'

Objective Tree Method – Procedure
Step 2 - Order the list into sets of higher-level and lower-level objectives

- **Order the each set of objective from high level to Low level objective.**
  - Example – For the Safety Set
    1. Machine must be safe
    2. Low risk of injury to operator
    3. Low risk of operator mistakes
    4. Low risk of damage to work piece or tool
    5. Automatic cut-out on overload

As you expand the list of objectives it should become clear that some are at higher levels of importance than others. Subobjectives for meeting higher-level objectives may also emerge, and some of the statements will be means of achieving certain objectives. This is because some of the questions that you will have been asking about the general objectives imply a 'means-end' relationship - that is, a lower-level objective is a means to achieving a higher-level one.
An example is the statement 'automatic cut-out on overload' in the list above. This is not really an objective in itself, but a means of achieving an objective - in this case, the objective of 'low risk of damage to workpiece or tool'. In turn, this 'low-risk of damage' objective is itself a lower-level objective to that of the overall 'safety' objective.
Your expanded list of objectives will therefore inevitably contain statements at various levels of specificity. In order to clarify the various levels that are emerging, rewrite your general list of objectives into ordered sets. That is, group the objectives into sets, each concerned with one highest-level objective. For example, one set might be to do with 'safety', another to do with 'reliability', and so on. Within each set, list the subobjectives in hierarchical order, so

that the lower-level ones are clearly separated as means of achieving the higher-level ones. Thus, for instance, your 'safety' list might look like this:

- Machine must be safe
- Low risk of injury to operator
- Low risk of operator mistakes
- Low risk of damage to workpiece or tool
- Automatic cut-out on overload

The list is now ordered into three hierarchical levels. It can sometimes be difficult to differentiate between levels of objectives, or different people in the design team may disagree about relative levels of importance of some objectives. However, exact precision of relative levels is not important, and you want only a few levels, about which most people can agree. For instance, in the above list, 'low risk of injury' might be considered more important than 'low risk of mistakes', but all three 'low risk' objectives can conveniently be grouped at about the same level.

The valuable aspect to sorting objectives roughly into levels is that it encourages you to think more clearly about the objectives, and about the relationships between means and ends. As you write out your lists in hierarchical levels, you will probably also continue to expand them, as you think of further means to meet subobjectives to meet objectives, etc.

When you have quite a lot of statements of objectives, it is easier to sort them into ordered sets if each statement is written onto a separate slip of paper or small card. Then you can more easily shuffle them about into groups and levels.

Objective Tree Method – Procedure
Step 2 – Generic List of Qualities / Objectives

- **Structural Qualities** – concern the structure of an artefact:
  - **Coherence**—the degree to which the parts of an artefact are logically, orderly, and consistently related; coherence is low if an artefact includes parts that, in some sense, do not fit in with the rest of the artefact.
  - **Consistence** (only for models)—the degree to which a model is free from conflicts.
  - **Modularity**—the degree to which an artefact is divided into components that may be separated and recombined; common requirements related to modularity are low coupling, i.e. modules are not overly related with each other; high cohesion, i.e. modules are highly related internally; and high composability, i.e. modules can be easily replaced and recombined.
  - **Conciseness**—the absence of redundant components in an artefact, i.e. components the functions of which can be derived from other components.

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Objective Tree Method – Procedure
Step 2 – Generic List of Qualities / Objectives

- **Usage qualities** describe how an artefact should work and be perceived in use situations:
  - **Usability**—the ease with which a user can use an artefact to achieve a particular goal
  - **Comprehensibility**—the ease with which an artefact can be understood or comprehended by a user (also called understandability)
  - **Learnability**—the ease with which a user can learn to use an artefact
  - **Customisability**—the degree to which an artefact can be adapted to the specific needs of a local practice or user
  - **Suitability—**the degree to which an artefact is tailored to a specific practice, focusing only on its essential aspects (also called inherence or precision)
  - **Accessibility**—the degree to which an artefact is accessible by as many users as possible
  - **Elegance**—the degree to which an artefact is pleasing and graceful in appearance or style (also called aesthetics)
  - **Fun**—the degree to which an artefact is attractive and fun to use
  - **Traceability** (only for methods)—the ability to verify the history of using a method by means of documentation

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Objective Tree Method – Procedure
Step 2 – Generic List of Qualities / Objectives

- **Management qualities** describe how an artefact should be managed over time:
- **Maintainability**—the ease with which an artefact can be maintained in order to correct defects, meet new requirements, make future maintenance easier, or cope with a changed environment.
- **Flexibility**—the ease with which an artefact can be adapted when external changes occur (similar to maintainability; related notions are configurability, evolvability, and extensibility).
- **Accountability**—the ease with which an actor can be made accountable for the workings of an artefact (a similar notion is auditability).

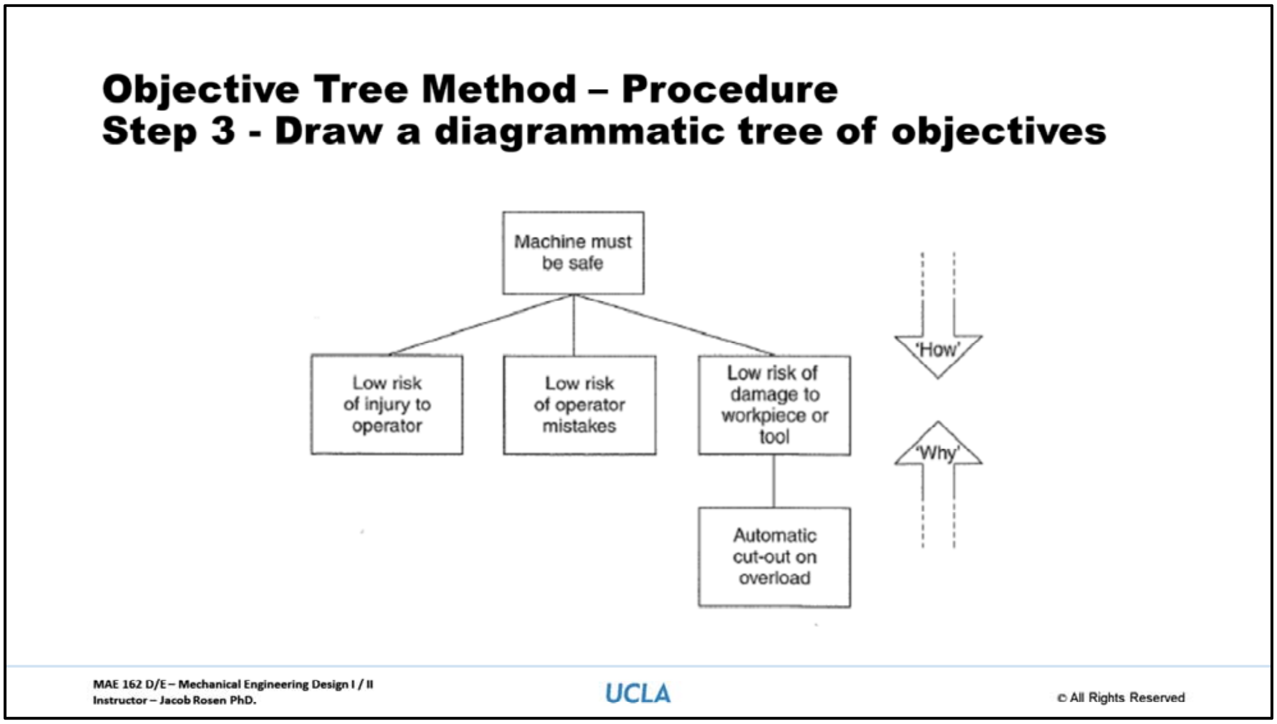
Objective Tree Method – Procedure
Step 2 – Generic List of Qualities / Objectives

- **Generic environmental qualities** mainly describe how an artefact should be structurally related to its environment:
  - **Expressiveness** (only for constructs and models)—the degree to which a set of constructs or a model is capable of representing the entities of interest in a Domain
  - **Correctness** (only for models)—the degree to which a model corresponds to the domain it represents (also called accurateness)
  - **Generality**—the degree to which an artefact is relevant not only for a local but also for a global practice Interoperability (only for instantiations)—the ability of an artefact to work together with other artefacts, in particular, to exchange data (related notions are openness, compatibility, and compliance with standards)
  - **Autonomy** (only for instantiations)—the capacity of an artefact to function without the involvement of another system
  - **Proximity** (only for models)—the degree to which independent aspects of a domain are captured by different constructs, and related aspects are represented by related constructs
  - **Completeness**—the degree to which an artefact includes all components required for addressing the problem for which it has been created
  - **Effectiveness**—the degree to which an artefact is able to achieve its goals
  - **Efficiency**—the degree to which an artefact is effective without wasting time, effort, or expense
  - **Robustness** (only for instantiations)—the ability of an artefact to withstand environmental change without adapting its construction
  - **Resilience** (only for instantiations)—the ability of an artefact to adapt itself when faced with major environmental change (related notions are degradability, survivability, and safety)

Objective Tree Method – Procedure
Step 2 – Generic List of Qualities / Objectives

- **5Es framework** that includes only five high-level qualities: efficacy, efficiency, effectiveness, elegance, and ethicality:
  - **Efficacy**—the degree to which an artefact produces desirable effects under ideal circumstances. For example, a weight-loss diet has high efficacy if people strictly following it actually lose weight.
  - **Efficiency**—the degree to which an artefact is effective without wasting time, effort, or expense. For example, a weight-loss diet is efficient if it is not expensive and does not require too much time to follow it.
  - **Effectiveness**—the degree to which an artefact produces desirable effects in practice. For example, a weight-loss diet has low effectiveness if people, due to various situational factors, are not able to follow it in their daily life. However, the diet can still have high efficacy; thus, efficacy and effectiveness are not the same.
  - **Elegance**—the degree to which an artefact is pleasing and graceful in appearance or style. For example, a weight-loss diet is elegant if it tastes good and is visually pleasing.
  - **Ethicality**—the degree to which the use of an artefact adheres to ethical norms. For example, a weight-loss diet including meat consumption may not be viewed as ethical according to some norms.

Attributes	Consequences
Safety	The vehicle provides accurate safety warnings.
	The vehicle has high safety and standard ratings.
Efficiency	The vehicle gets good mileage.
	The vehicle is energy efficient.
	The vehicle has high horsepower.
Cost	The vehicle is affordable.
	The vehicle has an extensive warranty.
	The vehicle is a hybrid (i.e., it splits power between electric and gas).
Performance	The vehicle has towing capabilities.
	The vehicle does not compromise speed and handling.
	The vehicle can be driven for longer distances (>400 miles).
Comfort	The vehicle provides a comfortable ride.
	The vehicle has a quality audio system.
	The vehicle is climate controlled.
	The vehicle comfortably fits a sufficient number of people.
Eco-friendliness	The vehicle has low emissions.
	The vehicle is environmentally friendly.



As you write out and shuffle your lists, you will probably realize that some of the subobjectives relate to, or are means of achieving, more than one higher-level objective. For example, the subobjective of 'low risk of damage to workpiece or tool' might be not only a means of achieving safety but also a means of achieving reliability. So a diagram of the hierarchical relationships of these few objectives and subobjectives might look like that in Figure 6.1. This diagram is the beginnings of a 'tree' which shows the full pattern of relationships and interconnections. It is not necessarily just a simple 'tree' structure of branches, twigs and leaves, because some of the interconnections form loops or lattices. The 'tree' is also normally drawn 'upside-down' - i.e. usually it has increasingly more 'branches' at lower levels - and so it might be better to think of the subobjectives as 'roots' rather than 'branches'.
It can sometimes be more convenient to draw the tree on its side, i.e. with branches or roots spreading horizontally. In order to help organize the relationships and interconnections between objectives and subobjectives, draw a complete tree diagram, based on your ordered sets of objectives. Each connecting link that you draw indicates that a lower-level objective is a means of achieving

the higher-level objective to which it is linked. Therefore working down the tree a link indicates how a higher-level objective might be achieved; working up the tree a link indicates why a lower-level objective is included.

Different people might well draw different objectives trees for the same problem, or even from the same set of objectives statements. The tree diagram simply represents one perception of the problem structure. The tree diagram helps to sharpen and improve your own perception of the problem, or to reach consensus about objectives in a team. It is also only a temporary pattern, which will probably change as the design process proceeds.

As with many other design methods, it is not so much the end product of the method (in this case, the tree diagram) which is itself of most value, but the process of working through the method. The objectives tree method forces you to ask questions about objectives, such as 'What does the client mean by X?' Such questions help to make the design objectives more explicit, and bring them into the open for discussion. Writing the lists and drawing the tree also begin the process of suggesting means of achieving the design objectives, and thus of beginning the process of devising potential design solutions.

Throughout a project, the design objectives should be stated as clearly as the available information permits; the objectives tree facilitates this

Objective Tree Method – Summary

- **Aim** - The aim of the objectives tree method is to clarify design objectives and sub objectives, and the relationships between them.

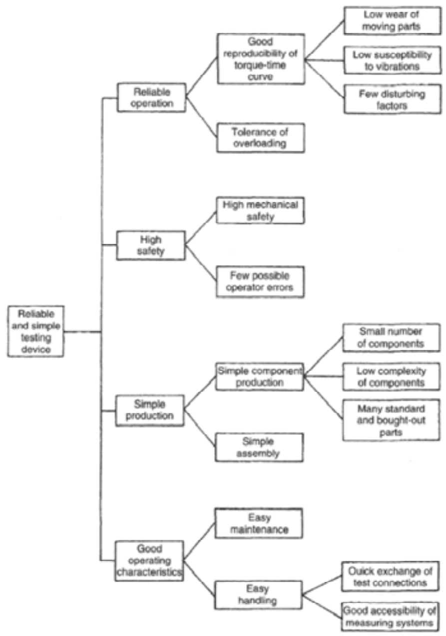
1. Prepare a list of design objectives. These are taken from the design brief, from questions to the client and from discussion in the design team.

2. Order the list into sets of higher-level and lower-level objectives. The expanded list of objectives and sub objectives is grouped roughly into hierarchical levels.

3. Draw a diagrammatic tree of objectives, showing hierarchical relationships and interconnections. The branches (or roots) in the tree represent relationships which suggest means of achieving objectives.

Objective Tree Method – Procedure
Example - Testing shaft connections subjected to impulse loads

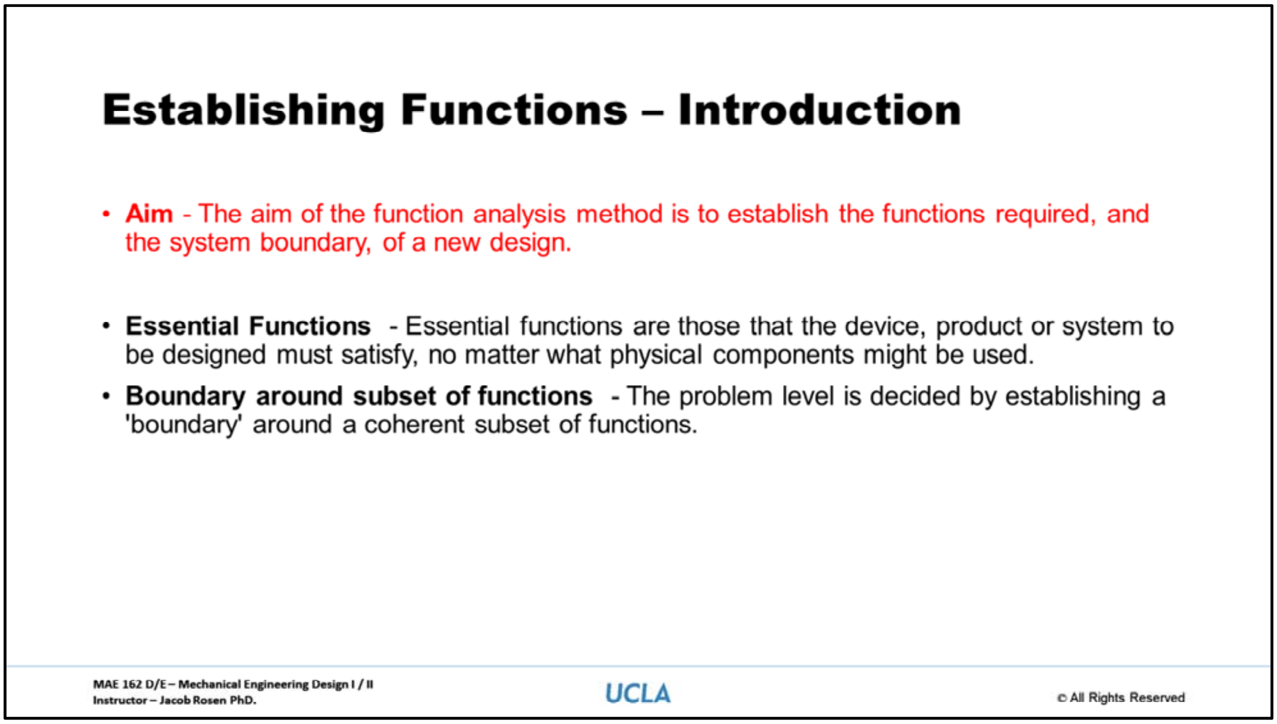
- The design problem was that of a machine to be used in testing shaft connections subjected to impulse loads.
- A typically vague requirement of a 'reliable and simple testing device' can be expanded into a much more detailed set of
- objectives
- 'Reliability' is expanded into
  - 'reliable operation'
  - 'high safety'.
- 'Simple' is expanded into
  - 'simple production'
  - 'good operating characteristics';
- In a case such as this, first attempts at expanding the list of objectives would probably produce statements at all levels of generality.
  - For example, asking 'What is meant by "simple"?' would have been likely to produce statements in random order such as,
  - 'easy maintenance',
  - 'small number of components',
  - 'simple assembly',
- Drawing these out in the hierarchical tree structure shows how they relate together.


Reliable and simple testing device
Reliable operation
Good reproducibility of torque-time curve
Low wear of moving parts
Low susceptibility to vibrations
Few disturbing factors
Tolerance of overloading
High safety
High mechanical safety
Few possible operator errors
Simple production
Simple component production
Small number of components
Low complexity of components
Many standard and bought-out parts
Simple assembly
Good operating characteristics
Easy maintenance
Easy handling
Quick exchange of test connections
Good accessibility of measuring systems

Steel Shaft Vs Carbon Fiber Shaft

Functional Analysis Method

Establishing Functions



We have seen from the objectives tree method that design problems can have many different levels of generality or detail. Obviously, the level at which the problem is defined for or by the designer is crucial. There is a big difference between being asked to 'design a telephone handset' or to 'design a telecommunication system'.
It is always possible to move up or down the levels of generality in a design problem. The classic case is that of the problem 'to design a doorknob'. The designer can move up several levels to that of designing the door or even to designing 'a means of ingress and egress' and find solutions which need no doorknob at all - but this is of no use to a client who manufactures doorknobs!
Alternatively, the designer can move down several levels, investigating the ergonomics of handles or the kinematics of latch mechanisms - perhaps again producing non-doorknob solutions which are functional improvements but which are not what the client wanted.
However, there are often occasions when it is appropriate to question the level at which a design problem is posed. A client may be focusing too narrowly on a certain level of problem definition, when a resolution at another level might be better, and reconsidering

the level of problem definition is often a stimulus to the designer to propose more radical or innovative types of solutions. So it is useful to have a means of considering the problem level at which a designer or design team is to work. It is also very useful if this can be done in a way that considers not the potential type of solution, but the essential functions that a solution type will be required to satisfy. This leaves the designer free to develop alternative solution proposals that satisfy the functional requirements.

The function analysis method offers such a means of considering essential functions and the level at which the problem is to be addressed. The essential functions are those that the device, product or system to be designed must satisfy, no matter what physical components might be used. The problem level is decided by establishing a 'boundary' around a coherent subset of functions.

Functional Analysis Method
Step 1 – Black Box

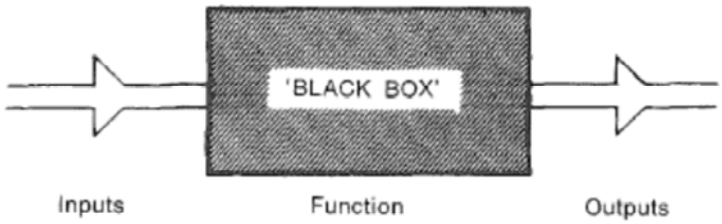
- **System Boundary** - The 'system boundary' is the conceptual boundary that is used to define the function of the product or device.
    - Boundary is defined too narrowly – Minor design changes
    - Boundary is defined too broadly - Radical design rethinking.
- **I/O Definition** - Asking the clients or users for definitions of the fundamental purpose of the product or device, and asking about the required inputs and outputs: from where do the inputs come, what are the outputs for.
- **Black Box -** Express the overall function for the design in terms of the conversion of inputs into outputs

The starting point for this method is to concentrate on what has to be achieved by a new design, and not on how it is to be achieved. The simplest and most basic way of expressing this is to represent the product or device to be designed as simply a 'black box' which converts certain 'inputs' into desired 'outputs'. The black box contains all the functions that are necessary for converting the inputs into the outputs (Figure 7.1).
It is preferable to try to make this overall function as broad as possible at first - it can be narrowed down later if necessary. It would be wrong to start with an unnecessarily limited overall function which restricts the range of possible solutions. The designer can make a distinct contribution to this stage of the design process by asking the clients or users for definitions of the fundamental purpose of the product or device, and asking about the required inputs and outputs: from where do the inputs come, what are the outputs for, what is the next stage of conversion?, etc.
This kind of questioning is known as 'widening the system boundary'. The 'system boundary' is the conceptual boundary that is used to define the function of the product or device. Often, this boundary is defined too narrowly, with the result that only minor

design changes can be made, rather than a radical rethinking. It is important to try to ensure that all the relevant inputs and outputs are listed. They can all usually be classified as flows of materials, energy or information, and these same classifications can be used to check if any input or output type has been omitted.

Functional Analysis Method
Step 1 – Black Box

- SISO
- SIMO
- MISO
- MIMO



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Functional Analysis Method
Step 2 – Transparent Box

- **Transparent Box** - Break down the overall function into a set of essential sub functions
- **No Systematic Way** - There is no really objective, systematic way of doing this; the analysis into sub functions may depend on factors such as:
  - The kinds of components available for specific tasks,
  - the necessary or preferred allocations of functions to machines or to human operators,
  - the designer's experience
- **Specifying Sub-Functions (Verb & Noun)** - It is helpful to ensure that they are all expressed in the same way. Each one should be a statement of a verb plus a noun
  - Example, 'amplify signal', 'count items', 'separate waste', 'reduce volume'.
- **Sub Function I/O** - Each sub function has its own input(s) and output(s), and compatibility between these should be checked.

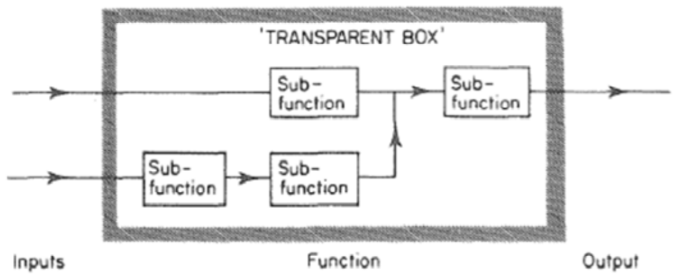
Usually, the conversion of the set of inputs into the set of outputs is a complex task inside the black box, which has to be broken down into subtasks or subfunctions. There is no really objective, systematic way of doing this; the analysis into subfunctions may depend on factors such as the kinds of components available for specific tasks, the necessary or preferred allocations of functions to machines or to human operators, the designer's experience, and so on.

In specifying subfunctions it is helpful to ensure that they are all expressed in the same way. Each one should be a statement of a verb plus a noun: for example, 'amplify signal', 'count items', 'separate waste', 'reduce volume'.

Each subfunction has its own input(s) and output(s), and compatibility between these should be checked. There may be 'auxiliary subfunctions' that have to be added but which do not contribute directly to the overall function, such as 'remove waste'.

Functional Analysis Method
Step 3 – Draw a block diagram

• MISO



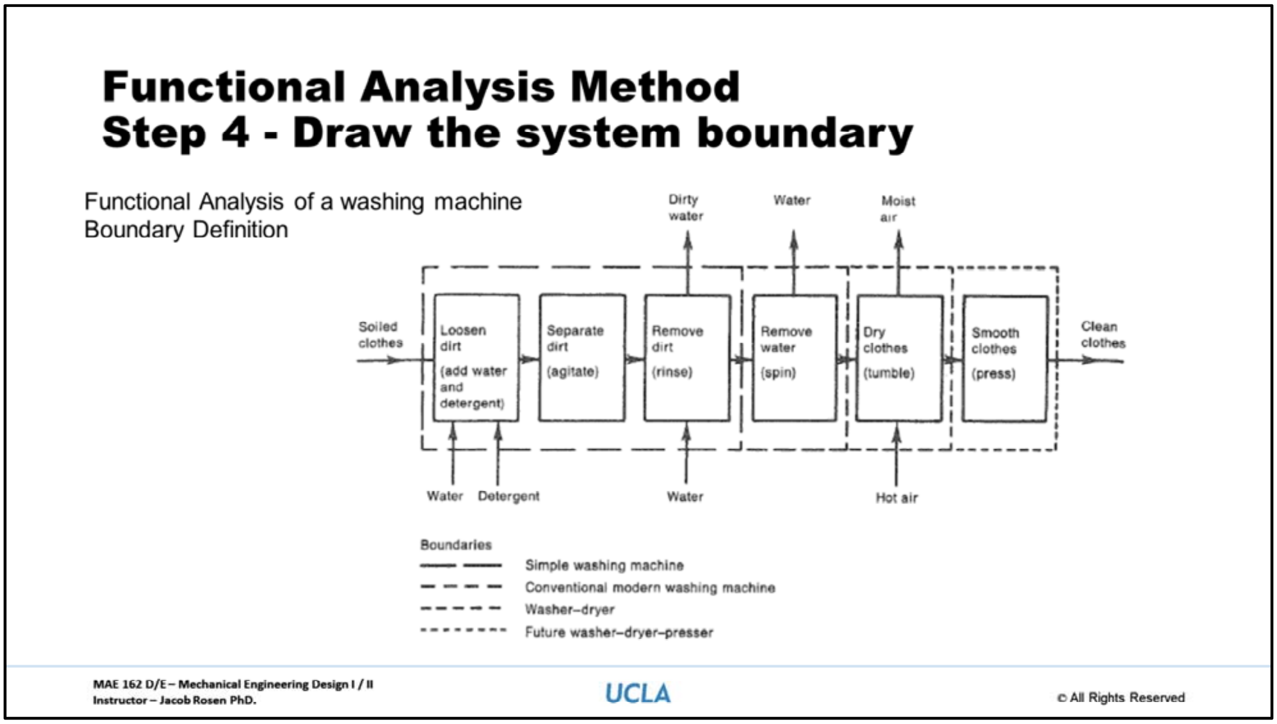
A block diagram consists of all the subfunctions separately identified by enclosing them in boxes and linked together by their inputs and outputs so as to satisfy the overall function of the product or device that is being designed. In other words, the original black box of the overall function is redrawn as a 'transparent box' in which the necessary subfunctions and their links can be seen

In drawing this diagram you are deciding how the internal inputs and outputs of the subfunctions are linked together so as to make a feasible, working system. You may find that you have to juggle inputs and outputs, and perhaps redefine some subfunctions so that everything is connected together. It is useful to use different conventions, i.e. different types of lines, to show the different types of inputs and outputs, i.e. flows of materials, energy or information.

Functional Analysis Method
Step 4 - Draw the system boundary

- **Precise Extent and Location of the System Boundary** - In drawing the block diagram you will also need to make decisions about the precise extent and location of the system boundary.
  - Example, there can be no 'loose' inputs or outputs in the diagram except those that come from or go outside the system boundary.
- **Narrow Definition of Sub Functions** - The boundary now has to be narrowed again, after its earlier broadening during consideration of inputs, outputs and overall function.
- **Boundary Around Subset of the Functions** - The boundary has to be drawn around a subset of the functions that have been identified, in order to define a feasible product. It is also probable that this drawing of the system boundary is not something in which the designer has complete freedom - as likely as not, it will be a matter of management policy or client requirements.
- **Different Product and Solutions** - Many different system boundaries can be drawn, defining different products or solution types.

In drawing the block diagram you will also need to make decisions about the precise extent and location of the system boundary.
For example, there can be no 'loose' inputs or outputs in the diagram except those that come from or go outside the system boundary.
It may be that the boundary now has to be narrowed again, after its earlier broadening during consideration of inputs, outputs and overall function. The boundary has to be drawn around a subset of the functions that have been identified, in order to define a feasible product. It is also probable that this drawing of the system boundary is not something in which the designer has complete freedom - as likely as not, it will be a matter of management policy or client requirements. Usually, many different system boundaries can be drawn, defining different products or solution types.



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Functional Analysis Method
Step 5 - Search for Components

- **Search for Components** - Search for appropriate components for performing the sub functions and their interactions
  - Example: , a 'component' might be defined as
    - A person who performs a certain task,
    - A mechanical component
    - An electronic device
- **Functions / Physical Devices -** The function analysis focuses on functions, and leaves the physical means of achieving those functions to later stage of the design process.

If the subfunctions have been defined adequately and at an appropriate levet then it should be possible to identify a suitable component for each subfunction. This identification of components will depend on the nature of the product or device, or more general system, that is being designed. For instance, a 'component' might be defined as a person who performs a certain task, a mechanical component or an electronic device. One of the interesting design possibilities opened up by electronic devices such as microprocessors is that these can often now be substituted for components that were previously mechanical devices or perhaps could only be done by human operators. The function analysis method is a useful aid in these circumstances because it focuses on functions, and leaves the physical means of achieving those functions to this later stage of the design process.

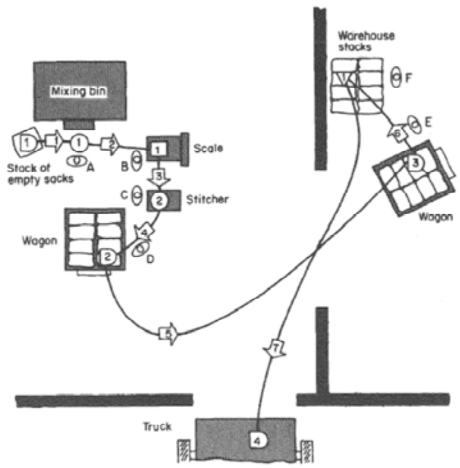
Functional Analysis Method
Step 5 - Search for Components

- Functions / Physical Devices

Functional Analysis Method
Example 1 – Feed Delivery System

- Factory where animal feedstuffs are bagged.
- The company wanted to try to reduce the relatively high costs of handling and storing the feedstuffs.
- A designer might tackle this task by searching for very direct ways in which each part of the existing process might be made more cost-effective.
- Broader formulation of the problem - the overall function - was represented in the following stages:
    1. Transfer of feed from mixing bin to bags stored in warehouse.
    2. Transfer of feed from mixing bin to bags loaded on truck
    3. Transfer of feed from mixing bin to consumers' storage bins.
    4. Transfer of feed ingredients from source to consumers' storagebins.

Functional Analysis Method
Example 1 – Feed Delivery System



- 1 Stocked sacks await filling
- 1 Man A lifts empty sack from stack and places it under spout for filling
- 1 Man A fills the 100-pound sack by gravity feed, manually controlling the rate of flow
- 2 Man A hands the bag to man B
- 1 Man B checks the weight and adds or removes material when necessary to adjust the weight to approximately 100 pounds
- 3 Man B hands the bag to man C
- 2 Man C folds and stitches the top of the bag
- 4 Man D takes the bag and loads it on wagon
- 5 Loaded wagon is pushed to warehouse
- 6 Bags are stacked by men E and F
- 1 Bags are stored awaiting sale
- 7 Bags are loaded on waiting truck, two or three at a time by handtruck, then delivered to consumer

YouTube https://youtu.be/jTageuhPfAM

The Founder 'Speedy System' – The Tennis Court Scene – The Assembly Line

YouTube https://youtu.be/algmMXZ7008

McDonald's: The Origins of a Fast Food Empire

YouTube https://youtu.be/ocXP1pLeqLM

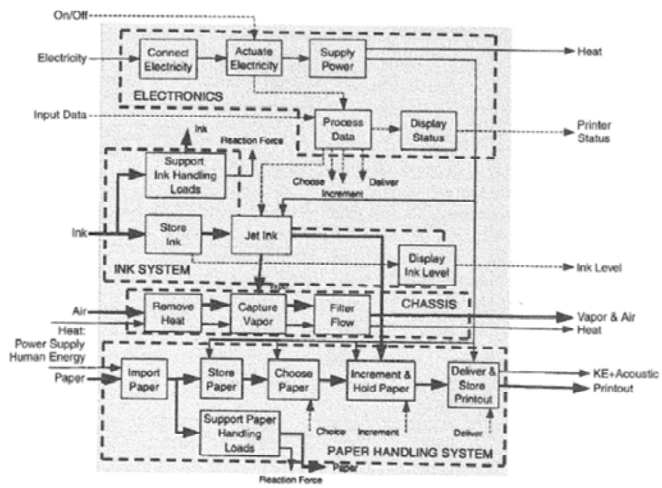
The Founder (2016) Persistence

One word... PERSISTENCE. Nothing in this world can take the place of good old persistence. Talent won't. Nothing's more common than unsuccessful men with talent. Genius won't. Unrecognized genius is practically a clich. Education won't. Why the world is full of educated fools. Persistence and determination alone are all powerful.

Functional Analysis Method
Example 2 – Feed Delivery System

- The following shows a function analysis for a desktop inkjet printer, with sub functions clustered. These clusters identify four primary modules for the printer:
  - Electronics,
  - Ink system (print cartridge),
  - Chassis and paper
  - Handling system.
- These modules depend, for the most part, on just one or two distinct connections between them.

Functional Analysis Method
Example 2 – Feed Delivery System



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Functional Analysis Method – Summary

- **Aim** - The aim of the function analysis method is to establish the functions required, and the system boundary, of a new design.

1. Express the overall function for the design in terms of the conversion of inputs into outputs. The overall 'black box' function should be broad - widening the system boundary.

2. Break down the overall function into a set of essential sub functions. The sub functions comprise all the tasks that have to be performed inside the black box.

3. Draw a block diagram showing the interactions between sub functions. The black box is made 'transparent', so that the sub functions and their interconnections are clarified.

4. Draw the system boundary. The system boundary defines the functional limits for the product or device to be designed.

5. Search for appropriate components for performing the sub functions and their interactions. Many alternative components may be capable of performing the identified functions.

Performance Specification Method

Setting Requirements

UCLA

Setting Requirements – Introduction

- **Aim** - Make an accurate specification of the performance required of a design solution.

- Design problems are always set within certain limits or constraints.
  - Examples For limits :
  - Cost
    - Selling Price - What the client is prepared to spend on a new machine
    - Buying Price - What customers may be paying as the purchase price of a product.
  - Geometry / Physics Attributes
    - Size - Acceptable size of the machine
    - Weight - Weight of a machine
  - Performance requirements
    - Engine's power rating
  - Legal requirements
  - Safety requirements

Design problems are always set within certain limits or constraints. One of the most important limits, for example, is that of cost: what the client is prepared to spend on a new machine, or what customers may be expected to pay as the purchase price of a product. Other common limits may be the acceptable size or weight of a machine; some limits will be performance requirements, such as an engine's power rating; still others might be set by statutory legal or safety requirements.

This set of requirements comprises the performance specification of the product or machine. Statements of design objectives or functions (such as those derived from objectives tree or function analysis methods) are sometimes regarded as being performance specifications, but this is not really correct. Objectives and functions are statements of what a design must achieve or do, but they are not normally set in terms of precise limits, which is what a performance specification does.

In setting limits to what has to be achieved by a design, a performance specification thereby limits the range of acceptable solutions. Because it therefore sets the designer's target range, it should not be defined too narrowly. If it is, then a lot of otherwise acceptable solutions might be eliminated unnecessarily. On the other hand, a specification that is too broad or vague can leave the designer with little idea of the appropriate direction in which to aim. Specification limits that are set too wide can also lead to inappropriate solutions which then have to be changed or modified when it is found that they actually fall outside of acceptable limits.

So there are good reasons for putting some effort into an accurate performance specification early in the design process. Initially, it sets up some boundaries to the 'solution space' within which the designer must search. Later on in the design process, the performance specification can be used in evaluating proposed solutions, to check that they do fall within the acceptable boundaries.

The performance specification method is intended to help in defining the design problem, leaving the appropriate amount of freedom so that the designer has room to manoeuvre over the ways and means of achieving a satisfactory design solution. A specification defines the required performance, and not the required product. The method therefore emphasizes the performance that a design solution has to achieve, and not any particular physical components which may be means of achieving that performance.

Setting Requirements – Introduction

- **Objectives and functions are not normally set in terms of precise limits** – Objectives and functions are statements of what a design must achieve or do, but they are not normally set in terms of precise limits, which is what a performance specification does.
- **Performance specification limits the acceptable solutions** - In setting limits to what has to be achieved by a design, a performance specification thereby limits the range of acceptable solutions.
- **Defined too narrowly – Eliminated acceptable solutions** - Because it therefore sets the designer's target range, it should not be defined too narrowly. If it is, then a lot of otherwise acceptable solutions might be eliminated unnecessarily.
- **Defined too broad - Vague / Inappropriate solutions** - A specification that is too broad or vague can leave the designer with little idea of the appropriate direction in which to aim. Specification limits that are set too wide can also lead to inappropriate solutions which then have to be changed or modified when it is found that they actually fall outside of acceptable limits.

Setting Requirements – Introduction

- **Accurate performance specification - Boundaries to the 'solution space'** - Define the solution space - There are good reasons for putting some effort into an accurate performance specification early in the design process. Initially, it sets up some boundaries to the 'solution space' within which the designer must search.
- **Performance specification - Evaluating proposed solutions** - Later on in the design process, the performance specification can be used in evaluating proposed solutions, to check that they do fall within the acceptable boundaries.
- **Specification define required performance not product** - A specification defines the required performance, and not the required product. The method therefore emphasizes the performance that a design solution has to achieve, and not any particular physical components which may be means of achieving that performance.
- **Performance Specification Method**
  - Help in defining the design problem
  - Leaving the appropriate amount of freedom so that the designer has room to maneuver over the ways and means of achieving a satisfactory design solution.

Design problems are always set within certain limits or constraints. One of the most important limits, for example, is that of cost: what the client is prepared to spend on a new machine, or what customers may be expected to pay as the purchase price of a product. Other common limits may be the acceptable size or weight of a machine; some limits will be performance requirements, such as an engine's power rating; still others might be set by statutory legal or safety requirements.

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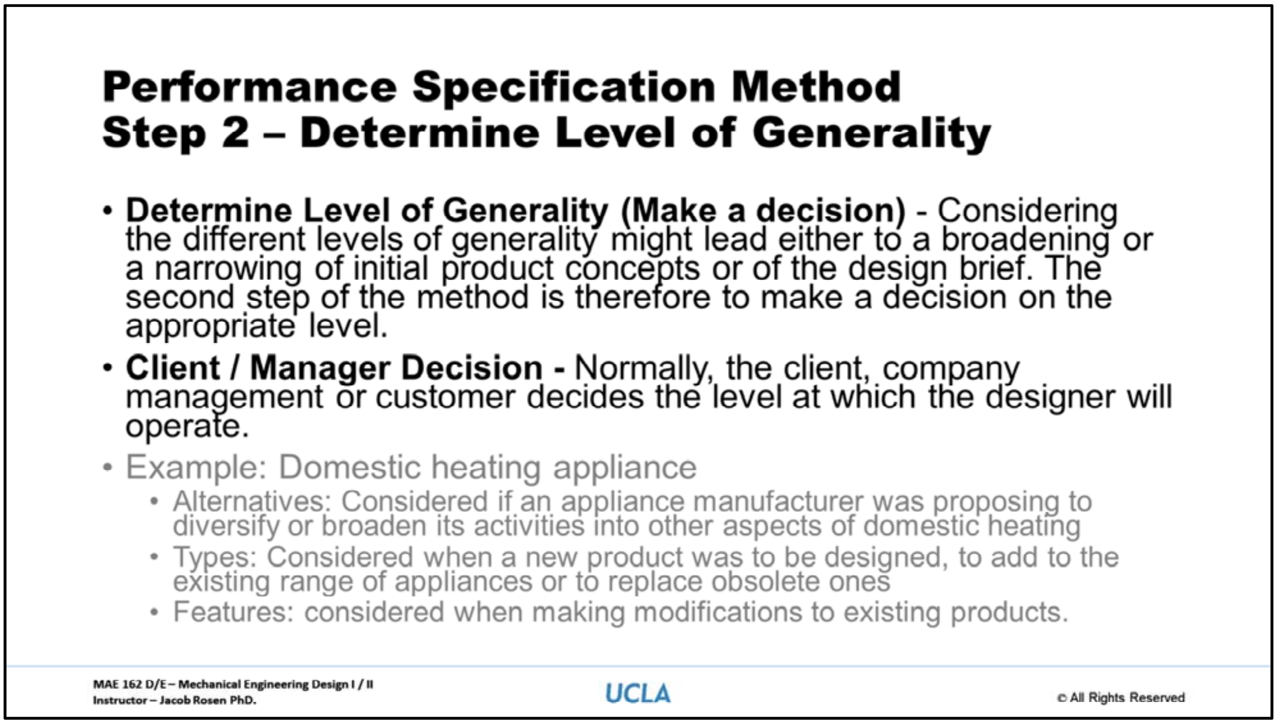
Performance Specification Method
Step 1 – Consider Level of Generality

- **Consider Level of Generality** - Consider the different levels of generality of solution which might be applicable
- **Classification (high to low)** - A simple classification of types of level, from the most general down to the least, for a product might be:
  - Alternatives
  - Types
  - Features.
- Example: Domestic heating appliance
  - Alternatives: moveable appliances, fixed appliances, central heating with radiators, ducted warm air, solar heating
  - Types: radiators, convectors, fuel types
  - Features: heating element, switches, body casing

It is important that a specification is addressed to an appropriate
level of generality for the solution type that is to be
considered. A specification at too high a level of generality may
allow inappropriate solutions to be suggested, whereas too low a
level (a specification which is too specific) can remove almost all of
the designer's freedom to generate a range of acceptable solutions.
So the first step is to consider the different levels of generality.
A simple classification of types of level, from the most general down
to the least, for a product might be:
4t product alternatives
4t product types
@ product features.
As an example to illustrate these levels, suppose that the product
in question is a domestic heating appliance. At the highest level of
generality the designer would be free to propose alternative ways
of heating a house, such as moveable appliances, fixed appliances,
central heating with radiators, ducted warm air, etc. There might
even be freedom to move away from the concept of an 'appliance'
to alternative forms of heating such as conservatories that trap solar
heat; or to ways of retaining heat, such as insulation. At the intermediate

level, the designer would have a much more limited freedom, and might only be concerned with different types of appliance, say, different heater types such as radiators or convectors, or different fuel types. At the lowest level, the designer would be constrained to considering different features within a particular type of appliance, such as its heating element, switches, body casing, supports, etc.



Considering the different levels of generality might lead either to a broadening or a narrowing of initial product concepts or of the design brief. The second step of the method is therefore to make a decision on the appropriate level.

Normally, the client, company management orcustomer decides the level at which the designer will operate. For instance, in the case of domestic heating appliances, the highest level of generality ('alternatives') would only be considered if an appliance manufacturer was proposing to diversify or broaden its activities into other aspects of domestic heating. The intermediate level ('types') would normally be considered when a new product was to be designed, to add to the existing range of appliances or to replace obsolete ones. The lowest level ('features') would be considered when making modifications to existing products.

The higher the level of generality that may be considered, then the more freedom the designer has in terms of the range of acceptable solutions. Of course, the higher levels also subsume the lower levels of specification; that is, the specification of features is part of the specification of types which is part of the specification of alternatives.

Performance Specification Method
Step 3 – Performance Attributes

- **Identify the required performance attributes** – Any product or machine will have a set of attributes, and it is these which are specified in the performance specification.
  - Examples: comfort, portability durability, speed, cost safety.
- **Source for performance attributes - Objectives tree / Functions Analysis** - Performance attributes are usually similar to, or derived from, the design objectives and functions. So if you have already prepared an objectives tree or a functions analysis, these are likely to be the source of your initial list of performance attributes.
- **Listing performance attributes independent of any particular solution** - A most important aspect to bear in mind when listing performance attributes is that they should be stated in a way which is independent of any particular solution. Statements of attributes made by clients or customers are often couched in terms of solutions, because they value some performance aspect which is embodied in the solution but they have not separated the attribute from a particular embodiment. Such solution-based rather than performance-based statements are usually unnecessarily restrictive of solution concepts.
- **Demands / Wishes** - The final list of performance attributes contains all the conditions that a design proposal should satisfy. However, it may become necessary to distinguish within this list between those attributes or requirements that are 'demands' and those that are 'wishes'. Demands are requirements that must be met, whereas wishes are those that the client, customer or designer would like to meet if possible.

Once the level at which designing is to proceed has been decided, work can begin on the performance specification proper. Any product or machine will have a set of attributes, and it is these which are specified in the performance specification. Attributes include such things as comfort, portability and durability, and key features such as speed, cost and safety.
Performance attributes are usually similar to, or derived from, the design objectives and functions. So if you have already prepared an objectives tree or a functions analysis, these are likely to be the source of your initial list of performance attributes.
A most important aspect to bear in mind when listing performance attributes is that they should be stated in a way which is independent of any particular solution. Statements of attributes made by clients or customers are often couched in terms of solutions, because they value some performance aspect which is embodied in the solution but they have not separated the attribute from a particular embodiment. Such solution-based rather than performance-based statements are usually unnecessarily restrictive of solution concepts.
For example, a client might suggest that the material for a

particular surface area should be ceramic tiles, because that is a satisfactory feature of an existing solution. But the essential performance requirement might be that the surface should be nonporous, or easy to clean, or have a smooth, hard texture, or simply have a shiny appearance. Acceptable alternatives might be plastics, metal or marble.

There may be a whole complex of reasons underlying a client or customer specification of a particular solution feature. It could be the whole set of attributes of a ceramic surface, as just listed, plus the mass which is provided by ceramic tiles, plus the colour range, plus some perceived status or other value which is not immediately obvious. A comprehensive and reliable list of performance attributes can therefore take some considerable effort to compile, and may well require careful research into client, customer and perhaps manufacturer requirements.

The final list of performance attributes contains all the conditions that a design proposal should satisfy. However, it may become necessary to distinguish within this list between those attributes or requirements that are 'demands' and those that are 'wishes'. Demands are requirements that must be met, whereas wishes are those that the client, customer or designer would like to meet if possible. For example, the requirement of a nonporous surface might be a functional 'demand', but availability in a range of colours might be a 'wish' dependent on the material actually chosen.

Performance Specification Method
Step 4 – State precise performance requirements

- **State precise performance requirements for each attribute (must do; not must be)** - A specification says what a product must do; not what it must be.
- **Need for research** - this may well require some careful research- it is not adequate simply to guess at performance requirements, nor just to take them from an existing solution type.
- **Quantified terms** - Wherever possible, a performance requirement should be expressed in quantified terms.
  - Example,
    - Maximum weight
      - Yes - Numerical Value
      - No - 'lightweight'.
    - Safety requirement - Escape from a vehicle-
      - Yes - Maximum time allowable for escape in an emergency
      - No - 'rapidly' or 'readily'.
    - Tolerance
      - Yes – Range
      - No – Specific value

Once a reliable list of attributes has been compiled, a performance specification is written for each one. A specification says what a product must do; not what it must be. Again, this may well require some careful research- it is not adequate simply to guess at performance requirements, nor just to take them from an existing solution type.

Wherever possible, a performance requirement should be expressed in quantified terms. Thus, for example, a maximum weight should be specified, rather than a vague statement such as 'lightweight'. A safety requirement - say, for escape from a vehicle- should state the maximum time allowable for escape in an emergency, rather than using terms like 'rapidly' or 'readily'.

Also, wherever possible and appropriate, a requirement should set a range of limits within which acceptable performance lies. So a requirement should not say 'seat height: 425 mm' if a range between 400 mm and 450 mm is acceptable. On the other hand, spurious 'precision' is also to be avoided: do not specify 'a container of volume 21.2 1' if you mean to refer to a wastepaper bin of 'approximately 300 mm diameter and 300 mm high'.

Performance Specification Method Example – Fuel Gauge

- **Lowest level of generality (Client)** - The problem was formulated by the client at the lowest level of generality
- **General formulation of the problem statement**:
  The design of a particular type of fuel gauge for use in motor vehicles. A gauge to measure continuously changing quantities of liquid in containers of unspecified size and shape, and to indicate the measurement at various distances from the containers.

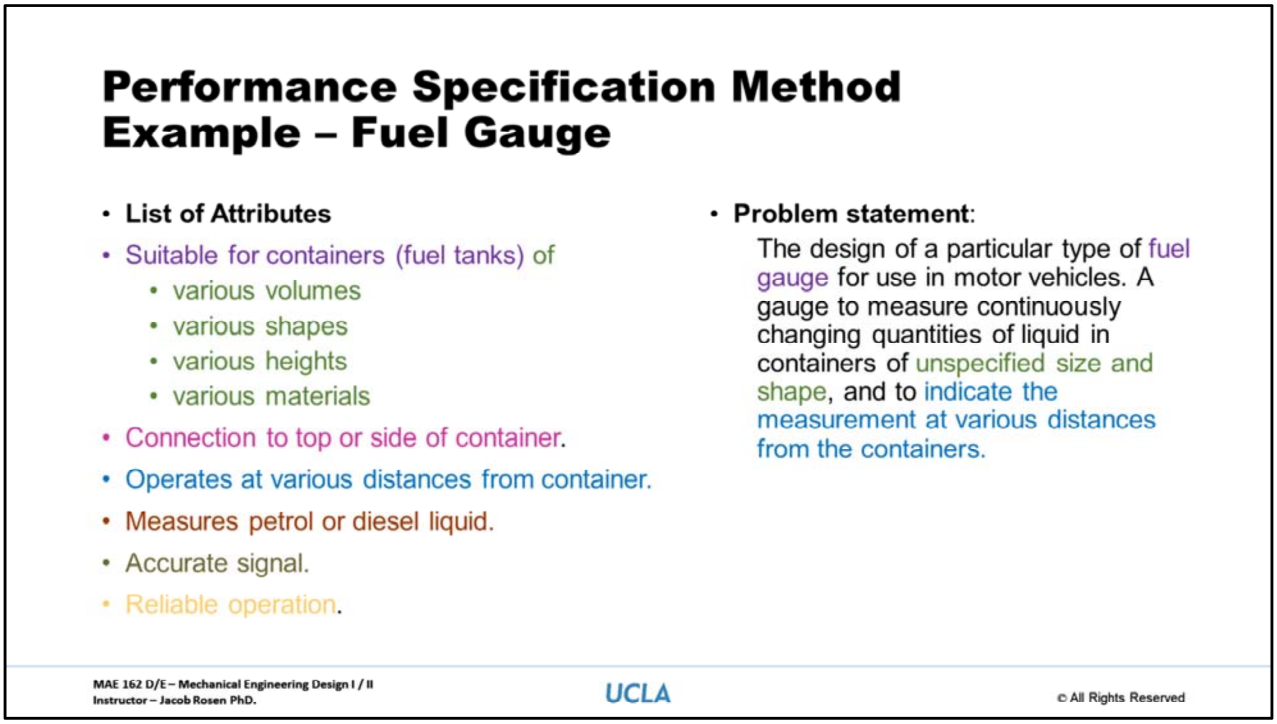
This problem was formulated by the client at the lowest level of generality: the design of a particular type of fuel gauge for use in motor vehicles. The initial general formulation of the problem statement was:

A gauge to measure continuously changing quantities of liquid in containers of unspecified size and shape, and to indicate the measurement at various distances from the containers.

The following list of attributes was then developed:

- Suitable for containers (fuel tanks) of
- various volumes
- various shapes
- various heights
- various materials.
- Connection to top or side of container.
- Operates at various distances from container.
- Measures petrol or diesel liquid.
- Accurate signal.
- Reliable operation.

The design team went on to develop a full performance specification, as shown in Figure 8.2. As in the previous example, they also distinguished between 'Demands' (D) and 'Wishes' (W). (Source: Pahl and Beitz, 1999.)



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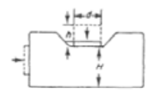
Specification

for Fuel gauge — Page 1

Changes	D or W	Requirements	Responsible
		1. Container, connection, distance	
	D	Volume: 20 – 160 l	
		Shape fixed or unspecified (rigid)	
	D	Material: steel or plastic	
		Connection to container:	
	W	Flange connection	
	D	Top connection	
	D	Side connection	
		H = 150 – 600 mm	
	W	d = ⌀ 71 mm, h = 20 mm	
	D	Distance from container to indicator:	
		≠ 0 m, 3 – 4 m	
	W	1 – 20 m	
		2. Contents, temperature range, material	
		Liquid — Operating range — Storage environment	
	D	Petrol or diesel — −25 to +65°C — −40 to +100°C	
		3. Signal, energy	
	W	Output of transmitter: electric signal (voltage change with quantity change)	
	D	Available source of energy: d.c. at 6, 12, 24 V	
		Voltage variation − 15 to +25%	
	D	Output signal accuracy at max. ±3%	
	W	±2%	
		(together with indicator error ±5%)	
		under normal conditions, horizontal level, v = constant,	
		able to withstand shocks of normal driving	
	D	Response sensitivity: 1% of maximum output signal	
	W	0.5% of maximum output signal	
	D	Signal unaffected by angle of liquid surface	
	D	Possibility of signal calibration	



Specification

for Fuel gauge — Page 2

Changes	D or W	Requirements	Responsible
	W	Possibility of signal calibration with full container	
	D	Minimum measurable content: 3% of maximum value	
	W	Reserve tank contents by special signal	
		4. Operating conditions	
	D	Forward acceleration ±10 m/s²	
	D	Sideways acceleration ±10 m/s²	
	D	Upward acceleration (vibration) up to 30 m/s²	
	W	Shocks in forward direction without damage up to 30 m/s²	
	D	Forward tilt up to ±30°	
	D	Sideways tilt max. 45°	
	D	Tank not pressurized (ventilated)	
		5. Test requirements	
	D	Salt spray tests for inside and outside components according to client's requirements	
	D	Pressure test for container 30 kN/m²	
		6. Life expectancy, durability of container	
	D	Life expectancy 5 years in respect of corrosion due to contents and condensation	
	D	Must conform with heavy vehicle requirements	
		7. Production	
	W	Simply modified to suit different container sizes	
		8. Operation, maintenance	
	W	Installation by non-specialist	
	D	Must be replaceable and maintenance-free	
		9. Quantity	
		10 000/day of the adjustable type, 5000/day of the most popular type	
		10. Costs	
		Manufacturing costs ⩽ DM 3.00 each	

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Performance Specification Method - Summary

Aim - Make an accurate specification of the performance required of a design solution.

The procedure is as follows:

1. Consider the different levels of generality of solution which might be applicable. There might be a choice between
   - product alternatives
   - product types
   - product features.
2. Determine the level of generality at which to operate. This decision is usually made by the client. The higher the level of generality, the more freedom the designer has.
3. Identify the required performance attributes. Attributes should be stated in terms which are independent of any particular solution.
4. State succinct and precise performance requirements for each attribute. Wherever possible, specifications should be in quantified terms, and identify ranges between limits.

Quality Function Deployment (QFD) Method

Determining Characteristics

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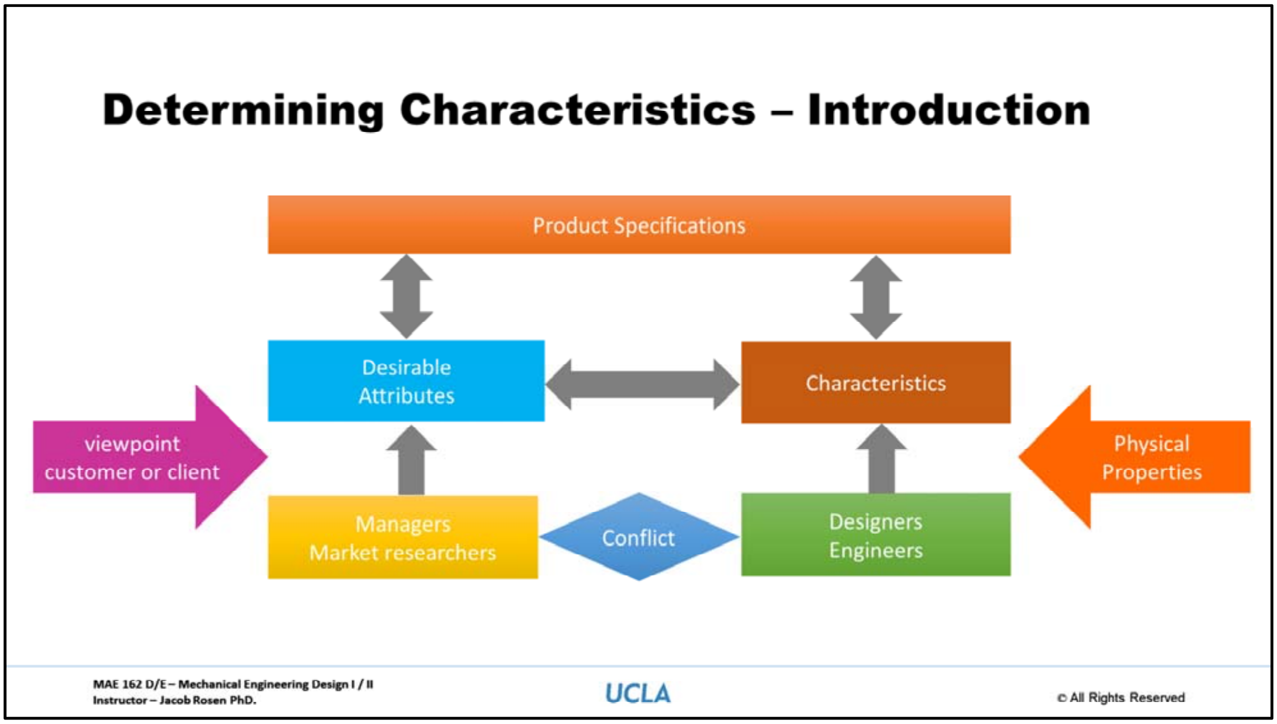

In determining a product specification, conflict and misunderstanding can sometimes arise between the marketing and the engineering members of the design team. This is usually because they focus on different interpretations of what should be specified. Managers and market researchers tend to concentrate more on specifying the desirable *attributes* of a new product (usually from the viewpoint of customer or client requirements), whereas designers and engineers concentrate more on a product's engineering *characteristics* (usually in terms of its physical properties).

The relationship between characteristics and attributes is in fact a very close one, and confusion can be avoided if this relationship is clearly understood. Designers make decisions about the product's physical properties, and thus determine its engineering characteristics; but those characteristics then determine the product's attributes, which in turn satisfy customers' needs and requirements. Thus, for example, the engineering designer may choose a particular metal casing for a product, of a certain gauge and surface finish, thus determining characteristics such as weight, rigidity and texture; these characteristics determine product attributes such as portability, durability and appearance.

With increased competition in all product markets, it has become necessary to ensure that this relationship between engineering characteristics and product attributes is properly understood.

In particular, it is necessary to understand just what customers want in terms of product attributes and to ensure that these are carefully translated into specifications of the appropriate engineering characteristics. This attitude towards product design is based on the philosophy of 'listening to the voice of the customer', and is reflected in an increased concentration on product quality. Design for quality is recognized as a major factor in determining the commercial success of a product.

Determining Characteristics – Introduction

- **QFD** - Quality Function Deployment method
- **Product Design Philosophy -** 'listening to the voice of the customer
- **Customer who buys a product is the most important person in determining the commercial success of a product** - The QFD method recognizes that the person who buys (or who most influences the buying decision for) a product is the most important person in determining the commercial success of a product.
  - **Commercial Success** - If customers buy it
  - **Commercial Failure** - If customers do not buy it, then the product – however 'well designed' it may be - will be a commercial failure.

Determining Characteristics – Introduction

- **QFD Approach**
- ‘The voice of the customer' has priority in determining the product's attributes.
- **Identify the Customers** - Identify who the customers are
- **Listen to the Customers** Listen carefully to what they say
- **Determine Engineering Characteristics** - Determine the product's engineering characteristics in the light of this.

Quality Function Deployment Method
Step 1: Identify customer requirements in terms of product attributes

- **Research Methods**
  - Focus groups
  - Questionnaires
- **Translation Customers Statements into Requirements (Attributes & Characteristics) -** Interpret the more general statements by customers e.g 'It's easy to use' to 'I don't like the color'. into more precise statements of requirements

The method starts with the identification of the customers and of their own views of their requirements and desired product attributes. There are various market research techniques that can be used to assist the gathering of information about customer requirements and preferences. These methods include product 'clinics' where customers are quizzed in depth about what they like and dislike about particular products, and 'hall tests' where various competing products are arranged on display in a room or hall and customers are asked to inspect the products and give their thoughts and reactions. The use of focus groups, questionnaires, etc., was introduced in the user scenarios method, Chapter 5.
Usually, of course, customers will talk about products both in terms of general attributes and specific characteristics: observations ranging from 'It's easy to use' to 'I don't like the colour'.
As in the performance specification method, it may be necessary to interpret the more general statements into more precise statements of requirements, but it is important to try to identify and to preserve customers' wishes and preferences, rather than to

reinterpret their observations into the designer's perceptions of what the customers 'really mean'. For this reason, words and phrases actually used by customers are often retained in statements of product attributes, even though they may seem to be vague and imprecise.

Quality Function Deployment Method
Step 2: Determine the relative importance of the attributes

- **Attributes' Importance** - Not all the identified product attributes will be equally important to customers.
  - Example, 'easy to use' may be regarded as much more important than' easy to maintain'.

- **Ranking Attributes** – Allocation of relative 'weights' to the set of customer-specified product attributes. Normally, a percentage value is set for each attribute, i.e. the weights for the complete set of attributes add up to a total of 100.

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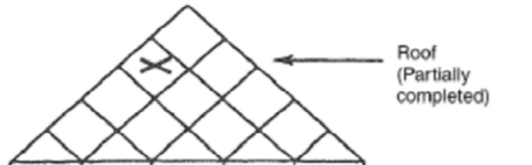
Example- Hand Held Cordless Drill



CAs	Relative Importance	+ Max. Power	+ Torque	+ Work Output	+ Mass	+ Tool Life
Can use tool continuously	25			9	3	
Tool is powerful	25	9	9			
Tool is multi-purpose	20	6	6			
Tool is easy to handle	20				9	
Tool is long-lasting	25					9
Imputed Importance		1.5	1.5	1.0	1.1	1.0
Units		W	Nm	kJ	kg	hrs
Competitor Values		85	1.5	25	1.59	1000
Targets						

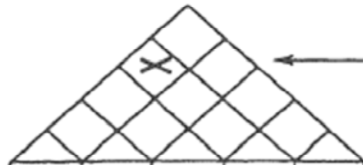
Quality Function Deployment Method
Step 3: Evaluate the attributes of competing products

- **Analyzing Competitive Products** - In a competitive market, the design team has ensure that its product will satisfy customer requirements better than the competitor products. The performance of the competition is therefore analyzed, particularly with regard to those product attributes that are weighted high in relative importance.
- **Designing New Improvement and Maintain Good Features** - In this step in the procedure not only highlights where improvements to the design team's product may be necessary, but also where this current product already has advantages over the competition, which should be maintained.

Customers often make judgements about product attributes in terms of comparisons with other products. For example, a car buyer may say that car A 'feels more responsive than car B'. This use of comparisons is perfectly understandable, given that customers are not usually experts and can only guess at what is possible in product design through observation of what some products actually achieve. Market research information is also often collected by methods of comparison between products.
In a competitive market, therefore, the design team has to try to ensure that its product will satisfy customer requirements better than the competitor products. The performance of the competition is therefore analysed, particularly with regard to those product attributes that are weighted high in relative importance. Some of these performance measures will be objective and quantitative, whilst some will be subjective comparisons as made by customers. However, even when objective measures can be made, these should be checked against customers' perceptions, which may not correspond with the objective measures.

In designing a new product, there may not be many competitor products, but that would be unusual; most product designs have to compete against existing products already on the market. In those cases where a design team is redesigning or improving an existing product, this step in the procedure not only highlights where improvements to the design team's product may be necessary, but also where this current product already has advantages over the competition, which should be maintained. The performance scores for the team's own current product and for the competition should be listed against the set of product attributes.

Example- Hand Held Cordless Drill



CAs	Relative Importance	+ Max. Power	+ Torque	+ Work Output	+ Mass	+ Tool Life
Can use tool continuously	25			9	3	
Tool is powerful	25	9	9			
Tool is multi-purpose	20	6	6			
Tool is easy to handle	20				9	
Tool is long-lasting	25					9
Imputed Importance		1.5	1.5	1.0	1.1	1.0
Units		W	Nm	kJ	kg	hrs
Competitor Values		85	1.5	25	1.59	1000
Targets						

Quality Function Deployment Method
Step 4: Draw a matrix of product attributes against engineering characteristics

- **Customers Provide Attributes** - Customers are not experts and therefore cannot usually specify their requirements in terms of the product's engineering characteristics that influence those requirements.
  - Example – Customers expect 'responsiveness' feels from a car
- **Engineering Team / Designers Provide Engineering Characteristics** - the design team to identify those engineering characteristics of their product that satisfy or influence in any way the customer requirements.
  - Example – Design team specify engineering characteristics such as overall weight of a car, and engine torque that will influence its 'responsiveness'.

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Instructor – Jacob Rosen PhD.

UCLA

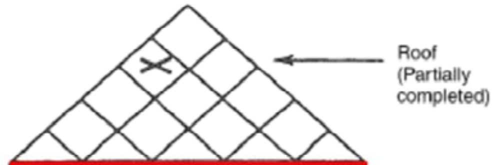
As suggested above, customers are not experts and therefore cannot usually specify their requirements in terms of the product's engineering characteristics that influence those requirements. For example, the car buyer may know what 'responsiveness' feels like, but is unlikely to be able to refer to this in terms of engine torque. It is therefore necessary for the design team to identify those engineering characteristics of their product that satisfy or influence in any way the customer requirements. For instance, the overall weight of a car, as well as its engine torque, will influence its 'responsiveness'.

The engineering characteristics must be real, measurable characteristics over which the engineering designer has some control. It is understandable for customers to be rather vague about their requirements, or to express them in frustratingly subjective terms, but the engineering designer can only work with the quantitative parameters of identifiable engineering characteristics. It is through the adjustment of the parameters of those characteristics that the designer influences the performance and/ or customers' perception of the product. Therefore it is often necessary to put considerable effort into identifying the relevant engineering characteristics and ensuring that each of these can be expressed in measurable units.

Of course, not all engineering characteristics affect all product attributes, and drawing up a matrix will enable the team to identify which characteristics do affect which attributes. It is usual to list the attributes, together with their relative weights, vertically, down the left edge of the matrix, and the characteristics horizontally, along the top edge. The attributes thus form the rows of the matrix, and the characteristics form the columns. Each cell of the matrix represents a potential interaction or relationship between an engineering characteristic and a customer requirement.

Down the right edge of the matrix can be listed the results of the evaluation of competing products, showing the scores achieved against the product attributes for the competing products and the design team's own current product. Along the bottom edge of the matrix is the usual place for recording the units of measurement of the engineering characteristics. If a product already exists and is being redesigned then the product's own values for these characteristics can also be inserted here, together with values achieved by competitor products.

Example- Hand Held Cordless Drill



CAs → ECs → Body → Supplementary Information

CAs	Relative Importance	+ Max. Power	+ Torque	+ Work Output	+ Mass	+ Tool Life
Can use tool continuously	25			9	3	
Tool is powerful	25	9	9			
Tool is multi-purpose	20	6	6			
Tool is easy to handle	20				9	
Tool is long-lasting	25					9
Imputed Importance		1.5	1.5	1.0	1.1	1.0
Units		W	Nm	kJ	kg	hrs
Competitor Values		85	1.5	25	1.59	1000
Targets						

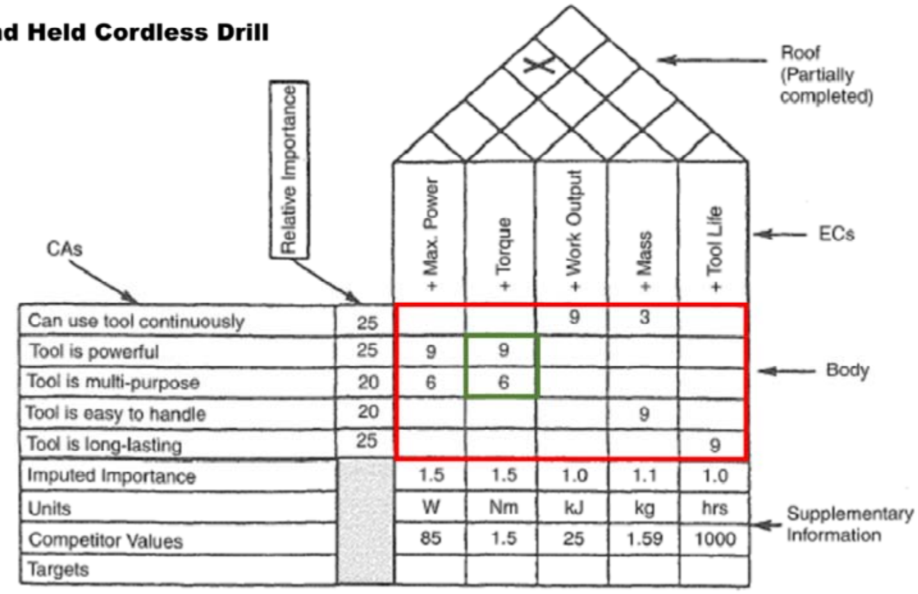
Quality Function Deployment Method
Step 5: Identify the relationships between engineering characteristics and product attributes

- **Identify cases where engineering characteristic influences** - product attribute By checking through the cells of the matrix it is possible to identify where any engineering characteristic influences any product attribute.
- **Identify Numerically the strength of that relationship** - The design team works methodically through the matrix, and records in the matrix cells wherever a relationship occurs, and the strength of that relationship. Sometimes numbers are used to represent the strength of the relationship

By checking through the cells of the matrix it is possible to identify where any engineering characteristic influences any product attribute. These relationships between characteristics and attributes will not all be of equal value. That is to say, some characteristics will have a strong influence on some attributes, whilst other characteristics might only have a weak influence.
The design team therefore works methodically through the matrix, and records in the matrix cells wherever a relationship occurs, and the strength of that relationship. Sometimes numbers are used to represent the strength of the relationship (e.g. 6 for a strong relationship, 3 for a medium-strength relationship, 1 for a weak relationship), or symbols can be used. When numbers are used, it is possible to enter a second value in each cell, which is the relative weight of the attribute multiplied by the strength of the relationship. The large scores amongst these values enable the design team easily to identify where the adjustment of engineering characteristics will have a large influence on customers' overall perception of the product. However, unless accurate measures

of the strength of the relationships can be established, it must be remembered that there is a spurious accuracy implied by the numbers.

Example- Hand Held Cordless Drill



CAs	Relative Importance	+ Max. Power	+ Torque	+ Work Output	+ Mass	+ Tool Life
Can use tool continuously	25			9	3	
Tool is powerful	25	9	9			
Tool is multi-purpose	20	6	6			
Tool is easy to handle	20				9	
Tool is long-lasting	25					9
Imputed Importance		1.5	1.5	1.0	1.1	1.0
Units		W	Nm	kJ	kg	hrs
Competitor Values		85	1.5	25	1.59	1000
Targets						

Quality Function Deployment Method
Step 6: Identify any relevant interactions between engineering characteristics

- **Interactions between engineering characteristics and themselves** - It is often the case that engineering characteristics interact with each other, particularly in terms of their influence on customers‘ perceptions of the product.
  - Example, a more powerful engine is also likely to be heavier, thus increasing the vehicle weight, and so not necessarily increasing its perceived 'responsiveness'.
- **Roof Matrix** - Working through the 'roof' matrix enables a systematic check to be made of the interactions between the engineering characteristics, and whether these interactions are negative or positive. However, many assumptions may have to be made about the final design when completing the 'roof' matrix, and it should be remembered that changes in the design concept may result in changes in these interactions.

It is often the case that engineering characteristics interact with each other, particularly in terms of their influence on customers' perceptions of the product. For example, a more powerful engine is also likely to be heavier, thus increasing the vehicle weight, and so not necessarily increasing its perceived 'responsiveness'. These interactions can be either negative or positive.
A simple way of checking these interactions is to add another section to the interaction matrix. This new section is usually added on top of the existing matrix, and because it provides a triangularshaped 'roof' to the matrix, and thus an overall'house' appearance, the resulting diagram is often referred to as the 'house of quality'.
Working through the 'roof' matrix enables a systematic check to be made of the interactions between the engineering characteristics, and whether these interactions are negative or positive. However, many assumptions may have to be made about the final design when completing the 'roof' matrix, and it should be remembered that changes in the design concept may result in changes in these

interactions.

Example- Hand Held Cordless Drill

CAs | ECs | Body | Supplementary Information

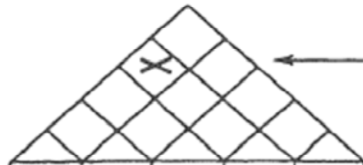
	Relative Importance	+ Max. Power	+ Torque	+ Work Output	+ Mass	+ Tool Life
Can use tool continuously	25			9	3	
Tool is powerful	25	9	9			
Tool is multi-purpose	20	6	6			
Tool is easy to handle	20				9	
Tool is long-lasting	25					9
Imputed Importance		1.5	1.5	1.0	1.1	1.0
Units		W	Nm	kJ	kg	hrs
Competitor Values		85	1.5	25	1.59	1000
Targets						

Quality Function Deployment Method
Step 7: Set target figures to be achieved for the engineering characteristics

- **Set targets values** - The design team set targets for themselves which would be better than the competition. Sometimes it may be necessary to conduct trials with customers in order to determine what would be acceptable target figures to set. This is similar to determining values in a performance specification.

In following this method so far, the design team will already have gained substantial insight into their product design, including customer perceptions of their product and of competing products, and how the engineering characteristics of the product relate to customer requirements. In this step of the procedure, the team determines the targets that can be set for the measurable parameters of the engineering characteristics in order to satisfy customer requirements or to improve the product over its competitors.
Of course, in a competitive situation it is important to know what the competitors achieve on the characteristics of their product, so detailed investigation of competitor products may be necessary.
The design team can then set targets for themselves which would be better than the competition. Sometimes it may be necessary to conduct trials with customers in order to determine what would be acceptable target figures to set. This is similar to determining values in a performance specification.

Example- Hand Held Cordless Drill



Roof (Partially completed)

CAs

ECs

CAs	Relative Importance	+ Max. Power	+ Torque	+ Work Output	+ Mass	+ Tool Life
Can use tool continuously	25			9	3	
Tool is powerful	25	9	9			
Tool is multi-purpose	20	6	6			
Tool is easy to handle	20				9	
Tool is long-lasting	25					9
Imputed Importance		1.5	1.5	1.0	1.1	1.0
Units		W	Nm	kJ	kg	hrs
Competitor Values		85	1.5	25	1.59	1000
Targets						

Body

Supplementary Information

Quality Function Deployment Method– Summary

Aim - Set targets to be achieved for the engineering characteristics of a product, such that they satisfy customer requirements.

The procedure is as follows:

1. Identify customer requirements in terms of product attributes. It is important that 'the voice of the customer' is recognized, and that customer requirements are not subject to 'reinterpretation' by the design team.
2. Determine the relative importance of the attributes. Techniques of rank-ordering or points-allocation can be used to help determine the relative weights that should be attached to the various attributes. Percentage weights are normally used.
3. Evaluate the attributes of competing products. Performance scores for competing products and the design team's own product (if a version of it already exists) should be listed against the set of customer requirements.
4. Draw a matrix of product attributes against engineering characteristics. Include all the engineering characteristics that influence any of the product attributes and ensure that they are expressed in measurable units.
5. Identify the relationships between engineering characteristics and product attributes. The strength of the relationships can be indicated either by symbols or numbers; using numbers has some advantages, but can introduce a spurious accuracy.
6. Identify any relevant interactions between engineering characteristics. The 'roof' matrix of the 'house of quality' provides this check, but may be dependent upon changes in the design concept.
7. Set target figures to be achieved for the engineering characteristics. Use information from competitor products or from trials with customers.

YouTube https://youtu.be/m2n0W1ycolY

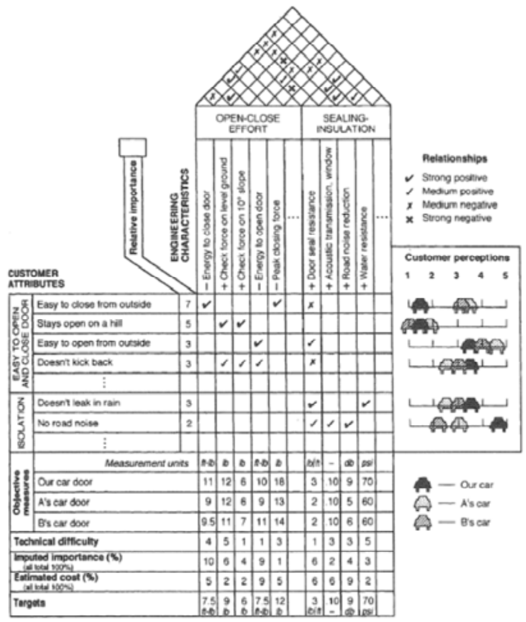
House of Quality / QFD (Quality Function Deployment) Intro (Example – Water Filter)

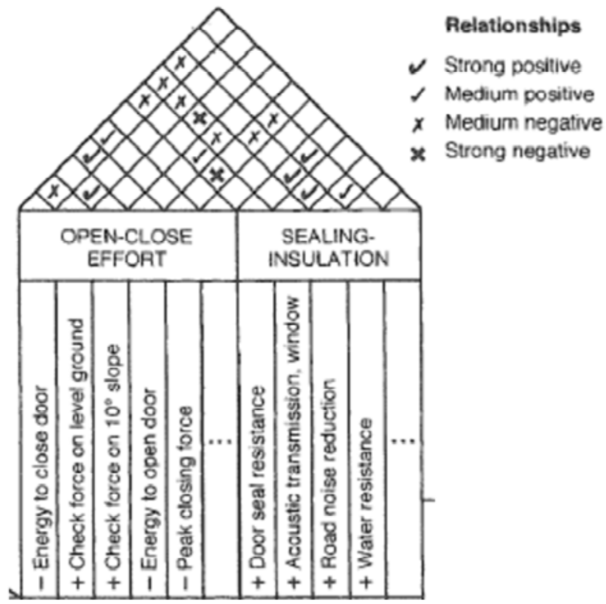
Quality Function Deployment Method–Example: Car Door

This example concentrates on selected attributes of one major product component, a car door. (Remember that car purchasers are said to be highly influenced in their choice of car just by the sound and feel of the door closing!) Figure 9.4 shows the first stage of developing and refining the set of product attributes from research on customer requirements. Using the objectives tree method enabled primary, secondary and tertiary levels of customer requirements to be identified and sorted into attribute 'bundles'. The relative importance weight of each attribute was also determined by market research surveys.

Using 'hall tests', customer perceptions of two competing products were established in comparison with their perceptions of the design team's own existing product. These customer perceptions were scored on a five-point scale, with a score of 5 representing the perceived best performance, and 1 representing the worst.

Part of the final, fully developed 'house of quality' is shown in Figure 9.5. The customer perceptions of the performance of competing products are shown graphically on the right. Objective measures of the relevant engineering characteristics were determined, and are shown below the matrix for the current and two competing products. Positive and negative interactions between ECs are shown in the matrix 'roof'. Finally, on the 'bottom line' are the targets set for a redesign of the car door, after considerations not only of imputed importance but also the technical difficulty and estimated cost of making improvements on the current design. (Source: Hauser and Clausing, 1988.)


OPEN-CLOSE EFFORT
SEALING-INSULATION
Relative importance
ENGINEERING CHARACTERISTICS
CUSTOMER ATTRIBUTES
– Energy to close door
+ Check force on level ground
+ Check force on 10° slope
– Energy to open door
– Peak closing force
+ Door seal resistance
+ Acoustic transmission, window
+ Road noise reduction
+ Water resistance
Relationships
Strong positive
Medium positive
Medium negative
Strong negative
Customer perceptions
1 2 3 4 5
EASY TO OPEN AND CLOSE DOOR
Easy to close from outside
Stays open on a hill
Easy to open from outside
Doesn't kick back
ISOLATION
Doesn't leak in rain
No road noise
Measurement units
Objective measures
Our car door
A's car door
B's car door
Our car
A's car
B's car
Technical difficulty
Imputed importance (%)
Estimated cost (%)
Targets


OPEN-CLOSE EFFORT
SEALING-INSULATION
– Energy to close door
+ Check force on level ground
+ Check force on 10° slope
– Energy to open door
– Peak closing force
+ Door seal resistance
+ Acoustic transmission, window
+ Road noise reduction
+ Water resistance
Relationships
Strong positive
Medium positive
Medium negative
Strong negative

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References

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    An Introduction to Design Science
    Authors: Johannesson, Paul, Perjons, Erik
  - Chapters 6,7,8,9
    Nigel Cross, Engineering Design Methods, Wiley

- Websites
  - Quality Function Deployment in Continuous Improvement

- Videos
  - Quality Function Deployment (QFD) and House of Quality – Car
  - Quality Function Deployment (QFD) and House of Quality – Water Filter