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III. Introduction

"Making" today is a "hype" word : there is a surge in making spaces and making hobbies that renders avoiding the subject an impossibility if you're anywhere near a creative or technical field. This wave of "creation" did not appear out of nowhere. Humans have been making throughout the latest three million years of their existence, and with each "making" advancement, society as a whole is affected and changed.

Homo faber designates man the maker. This expression infers that making is an essential characteristic of humanity. In other words, making is part of our humanity, a trait that distinguishes from other primates, animals or living beings. Some animals do use some tools, like … , but they use what they find at their disposal, they don't make, they don't create. Humans can make tools from the environment around them, and then use these tools to *change* that same environment. A stone polished and made into a … and it will be used to carve …. Creation is a characteristic attributed generally to the Divine, God, our maker, so it is no surprise that this ability not only separates us from beings around us, it also elevates us to a higher level, one that is closer to the Creator of all. [IV]

"Making" is not the only characteristic defining us as humans. One maker can create a tool, but this act of creation would not have a considerable impact if only one is made, and if only one person can make more. Making is not only changing the material world around us, but it is also creating. When the material and physical world is changed and modified, knowledge is created. If we are to make the same tool again, that same knowledge must be retrieved. Knowledge can be transmitted by language, the means we use to communicate and share ideas. if knowledge cannot be transmitted, at each time the same tool is to be made, either the same individual (the one who already has the skill and knowledge) must make it himself, or a different individual must go through a long process of trial to achieve the same result.

Based on this, the act of making is one by which humans can connect with their essence, changing the world around them for their own benefit, but it also is a mechanism for knowledge creation.

IV. Historical overview

The first products made by humans were probably the tools to hunt, then to cultivate and cook, and as human race progressed, its need for new adapted tools increased while the older ones still in demand where refined and optimized smoothly with time and experience.

Figure : Evolution of axes with time

History would designate this era as the paleolithic, or stone age, in which groups of humans used to hunt and gather food using their tools, settling in new territories with the change of seasons. By the end of that era, man was able to master his environment by growing plantation himself, cultivating the needed crops for food. This advancement prompted a change in human history, where man would settle in one area (preferably around a body of water) and grow his food around him. Humans started sedentary lives.

Thanks to the added stability, societies were growing in number, and an organization was needed to keep communal life in order. Specialization was needed to handle better the small society's needs which is where craftsmanship started to appear with individuals focusing on defined techniques and materials and becoming experts in making them. The bigger the group people, the more specializations are found.

Those crafts, developed over long periods of time and through countless trials, are then passed on through generations, allowing the craft to survive its craftsman, while this one shall be remembered thanks to his work. This was mostly the state of all small societies forming, these were villages that grew into towns and cities.

At that time, natural forms were the ideal model for specific purposes. Early artifacts were made of natural materials (clay, wood, metal,…). Man also created stereotypes of forms : each form is appropriate for specific purposes, adapted by intent or accident, refined with time and transformed by new technological possibilities.

Man who would specialize in manual labor creating products would be called a craftsman. The craftsman's home was his workshop. In fact, some sources claim workshops existed in India as early as 600BC. He and his family used to work, eat and sleep in the same space, which shows a mixture of life and labor. [X] This is referred to as "cottage industry", where very few participate in the making. The main makers are the apprentices, the journeymen and the masters. The three categories are reserved for men only.

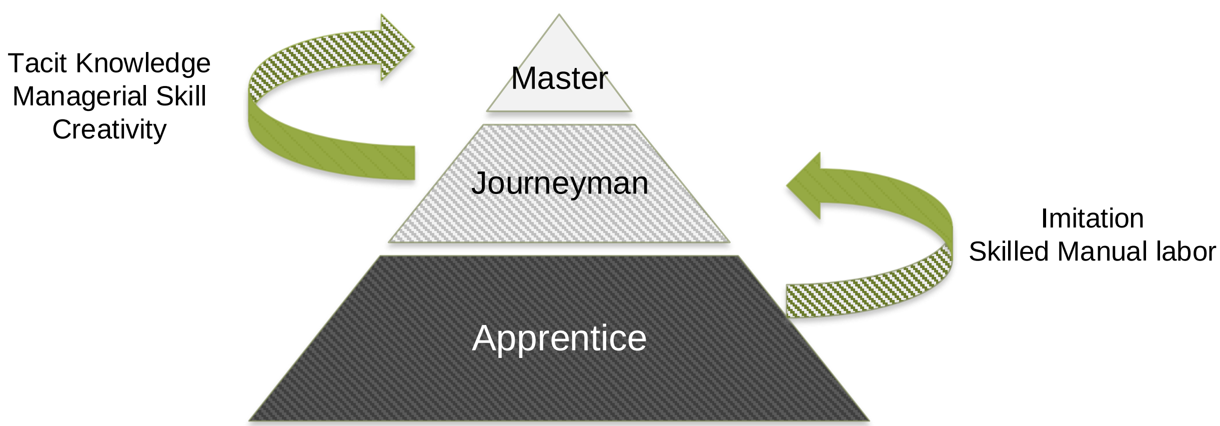
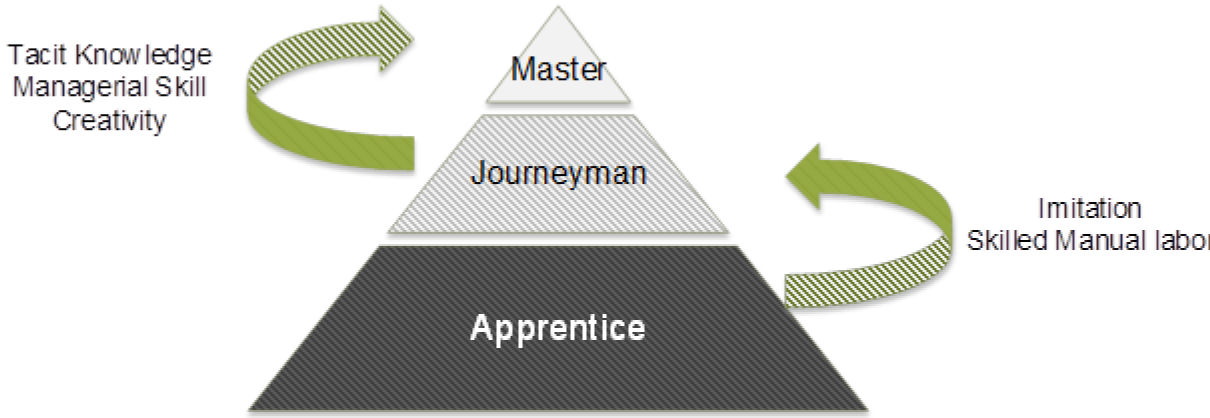


Figure 2: Workshop Hierarchy



This hierarchy functioned as follows : the master is the man in charge, he has the managerial power, but also, he's the master of the craft in question; he decides what's a good product and what isn't. The master oversees apprentices, who follow a training of 7 years, living and working with the master while the parents cover the costs. The apprenticeship would end with the subject presenting a *chef d'oeuvre* demonstrating his learned skills. Those are mostly obtained by "imitation": no creativity is in question, the apprentice is only tested for his ability to imitate, his skills to copy actions and techniques. After that his career starts as a journeyman.

The journeyman is not confined to the same workshop of his apprenticeship, he can choose to travel and work at different workshops seeking new opportunities. The journeyman would mostly travel based on supply and demand. Having a network of people and building a good reputation based on trust is a big asset. After 5-10 years, the journeyman can make a *chef d'oeuvre élevé* to convince that he can be a master himself. This challenge however has higher requirements than that of the apprentice: while the apprentice imitates, the journeyman should not only be able to use his knowledge to create, but also have good judgement and managerial skills.

The craftsmen were known and their products would be their fame and publicity.

Women were excluded from the "craftsmen group", even if they did share the same space with the craftsmen. They took care of cooking and cleaning, but they also practiced weaving and sewing. These activities today may be referred as crafts, instead, these activities were just considered "women" activities and not labor, as Penelope was weaving while waiting for Odysseus in the Odyssey and even some real-life queens, like Queen Edith, queen of Edward the Confessor and Queen Matilda, queen of William the conqueror, used to sew.

Workshops are a social space where people connect through some rituals, no matter how big or small, like having lunch together, or getting accustomed to certain environments related to the craft. They also connect people through direct teaching and informal advising, since workshops are a learning space for everyone. The face-to-face sharing of information is essential.

Once craftsmen were mastering their craft, and the basic community needs are met, more could be achieved, by grouping craftsmen with related masteries together and creating a network of skilled workers who can create bigger and more complex products. This " federation of autonomous workshops" was called "guilds" in medieval times, and aside from grouping craftsmen together, it also allowed them to share their tools, materials and transmit the knowledge from generation to generation[X]. A simple example would be jewelry making : it takes several craftsmen (a cutter/polisher of rocks, a goldsmith, ….) to make a simple piece of jewelry.

Residents of towns and villages were specializing in specific trades. The broader and more connected a network is, the more revenues the entire community would make, which means that individual makers were pushed to perfect their skills for their own benefit, and for that of their society and its economy. Some of these networks would include Silk weaving in Lucca, Italy in the thirteenth century, linen making in Germany in the fifteenth century, making woolen stockings in Norfolk England. In general, the regions specialize in products according to the natural resources at their disposal. Some of these networks still exist today, like the watchmaking industry in the Jura mountains in Switzerland, or leather shoe making in Italy, …[V].

Renaissance

Renaissance brought a change to the making world. While guilds were producing objects for regular use, artists were creating unique objects that granted them recognition and fame.

Following the ideology that craftsmanship extends to all sorts of labors, a product's quality was attributed to a workshop's location, not the craftsman himself. When the workshops got bigger and were grouped in guilds, it was even harder to recognize the maker.

Artists would need the same crafts and craftsmen, bur would rely on the originality of their product to gain popularity.

Before the 15th century, the status of artists was low. In the Middle Ages, there were three visual arts : painting, sculpture and architecture. Those artists worked close with craftsmen in the workshops. For example, painters were associated with druggists who would prepare the paints, sculptors were associated with goldsmiths and architects were associated with masons and carpenters.

Artist	Associated Craftmen
Painter	Druggist
Sculptor	Goldsmiths
Architect	Carpenters, masons

Table : Artists and their associated Craftsmen

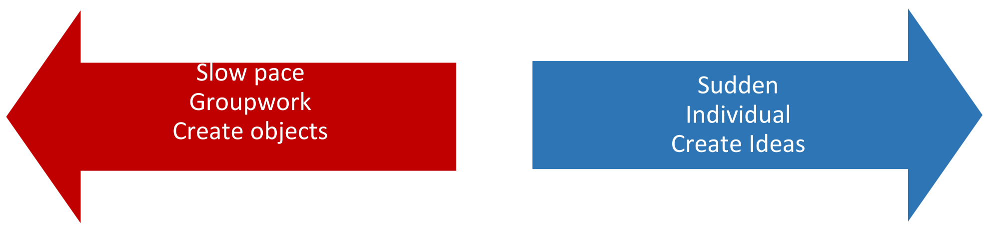
Until then, all products were three dimensional (3D) objects that had no drawings preliminary to their existence.

Drawings appeared during the Renaissance, with architects. This difference in 2D and 3D separated the architects from the other craftsmen or laborers. The drawings are ideas, which meant that architecture was an intellectual artistic labor not a manual one.

The 2D drawing was used as a true representation of the 3D world. The building, considered a product in this case, is built by a team of anonymous skilled people with accumulated knowledge working together on a construction site, realizing the artistic creation of an individual architect

Some regard ideas as superior to their representation (like the philosopher Plato), so intellectual labor as being more valuable than manual labor. Drawing is the base of the later created “Design” field, since Design is *disegno in* italian, which literally means drawing. Drawing can signify putting lines on paper, but it also is a representation of abstract ideas in the mind in physical reality.

Comparing artists and craftsmen, when craftsmen used to work in shared spaces as groups, artists used to work alone in isolation, since originality is associated with individuality. Craftsmen also needed the approval of their master for every produced piece, when the artist made his choices based on his own opinions, even when contradicted by his environment and his customer. The pace also differs for both, since the artists genius was sudden and fast, while the craftsman’s work was long.



Sennet [X] considers autonomy to be the biggest difference between those 2 groups.

Originality was important since it allowed the public to recognize the artist’s work. His name would be equivalent to a brand nowadays, which should be identifiable, since it affects the sales. This distinction then would carry a reward since originality and recognition would render the artists wealthier than craftsmen working in guilds. Some examples would include goldsmiths like Luccas Cranach, Lorenzo Ghiberti, Sandro Botticelli, … who took individual paths and made a name and a fortune for themselves.

Originality can also have negative consequences : if work is not satisfactory to the patron, the artist most likely wouldn’t be paid well.

Case study : Leo Da Vinci

Speaking of Renaissance Artists, it is imperative to mention Leonardo Da Vinci, who, besides being a widely known artist, was an inventor. Da Vinci started with a nine year apprenticeship at Verrochio’s workshop. Verrochio was a famous and busy master who was a painter, a sculptor and a goldsmith. Having learnt to copy his master’s work, Da Vinci was also curious about other subjects, which led him to Milano where he was commissioned to create military artifacts. He created submarines, time machines, wings for man to fly,… all of these projects can be identified today as engineering projects, not as artistic ones. Da Vinci enjoyed accumulating knowledge, testing theories, and finding new applications to established theorems, and all of this necessitated the production of artwork to test and study, yet not all of it was meant to be sold and used (as the case is in workshops and guilds).

Da Vinci was very aware of the natural and material limitations of creating physical objects, which pushed him to study more scientific subjects. He was consequently able to create different mechanisms and machines, which he represented with drawings accompanied by text, making them useful for representation, study and analysis, and joining the gap between creation and science. Since Da Vinci explored in different fields yet wasn't a professional in most of them, he was not always able to put his ideas into life, which means most of his inventions remained on paper due to physical and scientific limitations, however. prototyping and experimentation could open possibilities, even at a time where scientific curiosity wasn't at its peak.

The workshops/guilds however weren't as stable as they might seem. A common problem faced by workshops was the inability to transfer tacit knowledge: the steps and decisions a master would take instinctively, based on his experience. Originality is also hard to be passed over to the later generation. Another problem was the guilds themselves, not providing the best working conditions or recognition for craftsmen. Finally, a severe problem faced by workshops was that masters themselves couldn't dominate the market forever. It was risky enough for the workshop to pass from the command of one master to the other, like the case of Paganini's workshop that collapsed after his death. An even harder challenge was to stay relevant and in demand in a non-constant market, like the open market.

Industrialization

A real game changer would be the industrial revolution. The steam engine was invented during the 18th century. As this one progressed with time, and as technology was improving and spreading, the newly wealthy owners of plants needed to be in complete control of the making process. This wasn't the case, since Artisans and craftsmen where needed to create prototypes, molds, and basic tools, while the non-skilled workers only had to repeat their acts using the machinery available. Owners did try creating algorithms or machines that could copy the artisans behavior and intuition and replace them, leaving them alone in control, but their trials were unsuccessful.

Industrialization and the latter mechanization of the making process all started with the discovery of the steam engine in the 18th century. Ironically, Watt's steam engine was made in a workshop, it was a prototype of a piston using a surgical syringe . Workshops were still the place where things are made, which means that all machine parts that were manufactured at first, were manufactured in the workshop. Following its discovery, craftsmen weren't directly affected. However as the engine's applications multiplied, machines were intended to replace human tasks.

For example, a French inventor, Vaucanson, was commissioned by the king in 1741 to take charge and improve the degrading weaving industry in Lyon. To complete his job, he invented a machine that could measure and apply tension to threads (when humans could only touch and see those variables), and he made sure it could hold more threads and thus more colors than just 2 human hands. His machines could easily replace the workers in the weaving industry, and consequently he was assaulted in the streets of Lyon every time he set foot there for his invention was costing craftsmen their jobs.

Meanwhile, Europe was fully immersed in the enlightenment era, with philosophers and artists calling for emancipation. Diderot, a leader of the French enlightenment era and revolution, wrote the Encyclopedie between 1751-1772, it included a description of all labors. Most books and publications in that era targeted to elevate workers and laborers in general. Diderot's Encyclopedie targeted to elevate the thought of craftsmen and laborers to be admired.

Diderot encouraged youngsters to become apprentices and produce bad results, as these will allow reflection and improvement, and thanks to them the apprentice would know how to produce the good result. This thought was criticized for giving a “scientific approach” to crafts, since it doesn’t account for talent, and talent cannot be transmitted nor taught.

Diderot even tried learning by doing himself, however this was also criticized since small knowledge in certain crafts would not be enough to work in it.

Voltaire, another enlightenment writer, had a different point of view, where he encouraged the use of machines only when necessary, which is where man’s capabilities are limited. And this “human limitation” should not be perceived as burden, since crafted objects are distinguished thanks to their irregularities and flaws, the same can be said about their human makers.

Machines should be a tool supplementing and supporting human labor when necessary, and not replacing it. An example from Diderot’s Encyclopedie is the “papermaking” industry described at L’Anglée, where machines are used in the steps where tasks are too heavy, or the conditions are too harsh for humans to sustain.

Starting 1823, the knowledge needed to make machines was out for anyone to reproduce. And while the workshops were a mediator to the machine throughout the 19^{th} century, they slowly became opposers, and started focusing on individuality and variations and flaws to distinguish themselves from the machines.

Those machines were not designed by the craftsmen themselves, they were always conceived by someone else. Had they had a choice, they could make sure these machines would replace tedious repetitive tasks in which unskilled labor could be affected or harsh tasks as Voltaire advocated.

Factory owners, in general, cared mostly about making big revenues. The efficiency of the production cycle was directly proportional to revenues: the more products are made, the more the factory can sell, considering that the energy and other expenses are relatively constant. Factory owners were thus interested in increasing the efficiency of their workers through different strategies :

a. Having humans performing one task all day was proved to be more efficient for factory owners. Those workers were even paid depending on the pieces they make, which means they had no regular salary.
b. Studying the motion of efficient workers and copy it in a machine that could repeat tirelessly the same efficient moves and produce more than workers (Taylorism).

This “machine replacing humans” mentality failed ultimately. Machines could only imitate models, without innovating or commanding like craftsmen can. Despite the extensive effort to replace human workers, Taylor and Ford failed.

Machine can replace unskilled tasks. Highly specialized people have a list of procedure but also a culture, where their actions take place and how. With mechanization and technology, the mater’s challenge shifted from transmitting the knowledge to the journeyman to adapting the craft to a new environment.

Labor was mostly homogeneous in the 19th century, but with the expansion of mechanization, it became more and more segregated to skilled, semi-skilled and unskilled.

Factory as a machine

Not only products had to be prototyped, but also factory layouts and production lines

The factory is a place for work only (in general), and its architecture and organization are made in a way to optimize the efficiency of the production process. The factory transforms from a place enveloping the machines and people to a machine itself, expected to perform easing the flow of production.

The space in which prototypes are made is itself subject to being a prototype to be experimented with.

The factory moved to locations close to a source of energy, or closer to a mode of transportation to reduce costs and time. Train tracks were running along factory buildings, to facilitate the travel of raw materials and finished products. In some cases, the tracks would pass through the factory, like in New York for example where the tracks are elevated.

	FIRST INDUSTRIAL REVOLUTION	**SECOND INDUSTRIAL**	**THIRD**
LOCATION OF FACTORY	Outskirts	City	Both
	Mass production	Flexible accumulation	Mass customization
	Material products	Material products	Virtual products

Workshop	Factory
A place to live	Only work
Education and improvement of skill	Stagnation

The shape of the factory may be an L, H or E to compact the distribution, keep power sources nearby, create internal courtyards for outdoor work, and access additional light.

Multi-story buildings were also in use since land price was increasing and it decreased travel time of workers inside the factory. The multi-story buildings were problematic when steam power was the source of energy since it had to be transmitted with a system of belts but electricity made it way easier. Chutes and ramps are always used to decrease energy use taking advantage of gravity.

Factories embraced natural light (for it improved workers' performance and decreased cost of energy), architects consequently designed the factories with glass facades reinforced by steel.

Factories (the maker space) become the face of the progress, since their needs push for structural and material breakthroughs.

Those are engineering improvements that affect both the workers and the process flow. If efficient enough, they might lead to a decrease in work hours, like E. Owen Williams who modeled the Boots Company based on the production flow leading to a decrease of the workweek from 47.5 to 42.5 hours.

Architectural models were used in 3D (instead of only resorting to 2D sketches and drawings) in order to visualize the factory's layout and improve its flow (again here the factory is a product itself not just a space in which products are made)

Route models were adopted to facilitate the design of the factories.

The Butl Factory (Rhode Island 1912), had a 3d model of the interior of the factory, with cardboard rectangles cut to scale representing machinery to be experimented with until the best configuration is found. Also, strings of different colors can be used to map the material's movement to find the shortest path through the building.

These methods were in use till the 1950s with increased complexity of 3D models.

JOBS

The 20th century sees two new specializations born : industrial engineers and ergonomists.

Industrial Engineers combine managerial skills, production and mechanical knowledge.

Ergonomists make sure the workspace is healthy and safe for the workers.

Those new "jobs" appeared mostly as a result of the division of labor, since not the same person creating the design and manufacturing it. The worker might stand or sit all day repeating the exact same movements in an unnatural way. The division of labor did increase the efficiency of production lines, yet it contributed to the alienation of the creator to his creations and separated more the products from their human factors. [21]

At the time where Taylor was attempting to reduce the process time, he hired scientists for motion and time studies who could study human motion and replicate them in a machine. Some of these scientists were Frank and Lillian Gilberths, who were industrial engineers. Their concern was more of the workers' comfort. Based on their motion studies they developed knowledge related to different factors that can affect the worker's wellbeing in a production factory, like the seating, unnecessary moves, … their studies are viewed as the first works of ergonomics.

Architects were mostly in charge of embellishing and aesthetically designing offices, and management and client areas. They were not responsible for factory plan, however they were interested in improving it. At that time, shape followed function, which meant that engineers were appreciated, and architects disregarded. At that time design as a profession didn't exist, so engineering were the functional designers while architects were the aesthetic ones.

The big themes in this era are modernism, efficiency, mass production and economics.

Third industrial revolution : digital revolution, microprocessors, information technology,…

The boom is informational, global and networked, and manufacturing should be redefined to embrace these evolving industries.

With the digital revolution, most US of the factories were retooled or shipped offshore. Factories are decentralized, scattered around the world with control centers and production being separated.

Russia and China would make production a governmental issue while Japan would instead limit its imports. In fact, Japan was labeled a “nation of craftsmen”: following the second war, it became a cultural imperative to work well for the common good.[X]

Men can now be replaced by machines, which allows them more free time to pursue leisure activities. Now that more time is available, some choose to be makers, for their own enjoyement. With DIY you are not only worker, you are also author and financer and developer.

There is no stability for workers, cause some skills might be needed now and then unneeded tomorrow. Since customization is the new trend, the market unpredictable.

A big part of labor is also becoming “immaterial labor”, creating immaterial objects, such as knowledge, information and communication

We have the birth of clustered regions for knowledge production in the 1980s, like the Silicon Valley and some Indian cities like Bangalore and Hyderabad.

More geometric and simple forms, celebrating rationality, standardization and mass production.

Here production is not linear nor repetitive anymore , it’s a network.

Unskilled workers are needed anymore, we need specialists, programmers, scientists,

During that evolution, and since most products were mass produced and consumed, there was a need to create standards, like a standard way of sketching, modelling, defining basic shapes,…. This lead to the creation of new specializations, that necessitated the basic drawing and sketching skills acquired in Art, yet a mechanical and standardized systemization acquired in sciences. Art schools who tried adding the technical parts failed, which did lead to a new specialty, and the creation of the modernist era.

This era, filled with mass production and massive sales was followed by the post-modernist era, where acquiring products was not a challenge anymore, considering the decreased prices. Brands had to find a way to differentiate themselves and become more appealing to customers.

This was done by adopting an identity for the brand, that will be transmitted to its user, and this identity is mainly created and sustained with all of the products thanks to a designer who will assure this conformity.

However as products grew in complexity, more people needed to participate in their conception and making, which led to the creation of today's big R&D departments that are proven to be more ineffective each passing day.

"Product development" did exist for a very long time, it actually never ceased to exist, it just took different forms, names and shapes throughout history. And comparing the different stages of this history, we can see how the product making evolved from being an individualistic activity to a group activity due to the complexity of today's products, and the diversity yet specificity of the different specializations that do tackle the same issue. If at a certain point, the different players rendered the making process a better one, this is not the case today, yet no action is being taken to reform this.

In this thesis, we shall propose bringing back product development to the hands of an individual (or a handful of them), this one shall not belong to any of the specializations available today (product developer, architect, mechanical engineer, electronic engineer,…) but will have his own formation and education that includes the search of meaning and creativity of the designer combined with the problem solving mentality of the engineer.

Robotic arms existed since 1921, but they weren't used in assembly and production till 1954, when Unimation created a precise arm. This one was used by GM. Robotic arms are very important in some industries where some tasks are difficult or dangerous. For example, in the automotive industry, they can lift more load than humans can, they spare them from danger (like spray painting's fumes and complete tasks that are hard for humans to reach in tight spaces like welding and assembly.

Workers then are less endangered, faster and more precise production

The factory spaces are changed with areas of comfortable seating on the factory floor where workers can meet and discuss their work. The office space is more flexible with wide use of partitions to provide a blend of privacy and accessibility to encourage communication.

Creativity is fostered in places where there is less hierarchy and the company's organization is more flat. Where employees can move around and exchange ideas.

The space should be a combination of a private, team and communal facilities on a highly adaptable basis.

[VI]

V. NPD Process

Today's product development process was created to fill consumer demand or an opportunity in the marketplace. The process takes the product from conception to market.
Understanding the user needs and satisfying them require Prototypes that are usually developed in the conception and development phase.

Prototypes can be used as part of the development of design ideas, check the functionality of the product and its feasibility. It can also be tested in different use-case scenarios to identify its points of failure.

Informative system design is the entity that receives the users needs and wants, the designers who attempt to understand these needs, and attempt to satisfy them giving the resources, cost and technologies available

The new product development process is a linear procedure. Even for information processing systems, the usual linear procedure should be replaced by a prototype one at some point.

Most procedures are based on one particular development strategy, in which a set of activities is carried out serially.

The New Product Development (NPD) process is defined as the sequence of stages and activities that enable a company to conceive, design and market a new product.
It is a structured process, in which the goal is to speed up the operation.
If a company is interested in innovation, it may have a Fuzzy front-end.

Product development process can vary slightly depending on the design aspects and goals considered.
There are three models : design as problem-solving, design as phases and design as different levels of abstractions.

This study focuses on the problem-solving aspect of design, where a group of designers would consider the wants and needs of the users and provide them with solutions for existing problems.

Problem solving has a common process in different fields. It is called "the empirical cycle by de Groot and has the following sequence :

Observation-supposition-expectation-testing-evaluation.

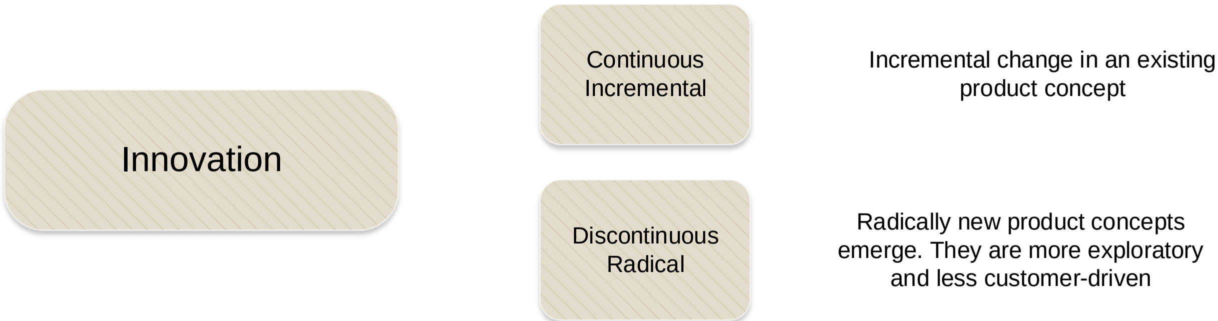
This procedure portrays the cycle of prototyping, where the designer observes a problem, studies in his imagination some possibilities to fix it and expects what the outcomes would be. The prototype would be built to test that solution and evaluate it. Based on that, the designer would have more insight on what would work and what wouldn't, and conceive a new solution, restarting the cycle.

It is a trial-and-error process that relies on imagination first, and testing reality later, with many iterations. The same cycle ca be implemented differently in a different field.

This procedure is very linked to knowledge creation and its process can be compared to one of scientific inquiry.

Innovation can be time-consuming since there is no specific path to follow. However once the product/ idea is identified, the company would follow a defined process that would minimize time to test, produce and market in order not to lose a market opportunity.

What kind od innovation ? Radical or incremental ? (PYRAMID)



Product development can be classified in 3 different parts :

[23]

Sequential :

A structured NPD process is important for the following reasons :

a. Making the decision-making process explicit
b. Insuring no product requirements are left-out
c. Easing information gathering

The Product development cycle includes different departments of the company including design, engineering, production and marketing.

The ideas to be developed can be pitched by the marketing department, since that one conducts surveys and analyzes market trends, as well as keeps up with customers and users receiving their opinions and complaints concerning previous purchased products.

Ideas can also be conceived by the R&D department that includes both designers and engineers who might have an innovative design or function.

Either way, it is up to the R&D department to implement and develop the idea suggested and make it come to life in prototypes.

Having a well-constructed hierarchy is advantageous where employees know their role. This hierarchy can also be disadvantageous at times due to the routine and the process bureaucracy.

It's a sequential process.

Start-ups and small companies are very frequent today. Their small size, drive to innovation and lack of hierarchy may be confusing but also allow more flexibility for employers and workers to be more dynamic and innovative. Small and medium enterprises represent 90% of the total amount of companies.

Integrated :

Some companies adopt an integrated model where designers can negotiate with other functional specialists to achieve more successful results. To reach that end, the designer should be skilled to manage both the creative and implementation phase.
(both of these phases are questioned in prototypes)

The design process :
" the search for a solution through the vast maze of possibilities within the problem space… Successful problem solving involves searching the maze selectively and reducing it to manageable solutions" (Simon, 1969)
The design process in this problem-solving process is systematic. It strives to be objective, playing down the designer's preferences and inhibition.
Man is reduced to a mechanical machine, and the product must fit it thanks to anthropometrics.
Design quality is objectively measured : intuition and subjective preference are not welcomed.

So here design and prototyping is less explorative and more like a method to test and evaluate solutions

[22]

Marketing team :
Would communicate the customers' needs in order to provide suitable products. They would specify requirements, competition, target market, prices, and consumer needs. [15]

Manufacturing team :
This department aims at making the manufacturing process simpler. They usually ask for product changes to accommodate a dominant design, use more standard parts and the machineries and technologies already in possession of the company.
Designers should be well informed of these specifics to create products satisfying them. Knowing the resources and skills available, designers can improve product quality, lower costs and accelerate the overall process by reducing the number of changes to be made. [15]

Problems faced :
The designer tools are different than those used by professional around him. The design team would use a visual language, have different implicit approaches and use intuitional and qualitative knowledge, referred to as delta knowledge.

Delta knowledge :

While the actors participating in the product development cycle (marketing, production, company board, … would be more accustomed to gamma and beta knowledge. For example, the production team is mostly educated in a scientific approach (beta knowledge) while the managers are more responsive to verbal and numeric language (gamma knowledge)

Delta knowledge is defined as "the world of the practical philosophy, the world of reflection in action" according to Gilles and Paquet's *On delta knowledg*e.[16] this world starts with the practical (not the theoretical), and the problem or "issue" comes before theory. Reflection in action is a technique that eliminates misfits and ensures a good fit. Here, a professional designer can create knowledge by making prototypes that solve issues [17]

This type of knowledge concerns timely and specific concerns, not general ones. The subject reflects on his experience and acquires new knowledge by doing. A *know-how* instead of a *know-what.*

Production of delta knowledge follows rules that are implicit, overlapping, diverse, contextually dependent, subject to exceptions and modifications.[18]

The designer does create this knowledge by finding a form that doesn't exist yet in a context that is permanently evolving.

This method is characterized as an experimental utopia by Lefebvre, where the designer enjoys an exploration through the visual and the imaginary, attempting to solve at best a real problem, which surpasses the usual forms of knowledge as hypotheses.

Design in the NPD

There is a disagreement on where design would belong in the NPD. Some consider design as part of the Product development phase of the NPD while others consider it as a phase of its own.[25] Since this study considers a designer any professional conceiving, building and testing the product no matter his background, design will be considered both a separate phase and as part of the product development process.

The role of design teams in NPD is to optimize function, value and appearance of corporate products by creating and developing concepts. [24]

Design in product development focuses on 2 things :
Aesthetics :The product's appeal to the human senses, intertwined with the symbolic and experimental value of a product
Usability : Comprehensibility of a product and its ease of operation. This can also contribute to a product's functionality or utility, reducing manufacturing costs. [25]

Today the designer is more of an integrator, a catalyst between the different teams [24]

VI. Technologies for prototyping

1. Sketches and Technical drawings

The drawing, whether on paper or the computer serve to visualize form. [VIII]
It was first adopted by architects in the Renaissance as a way to transform ideas from an abstract nature to a more tangible and visual mean, without resorting to the skills or manual labor necessary to construct it.

Technical drawings can be described as sketches that can be understood and interpreted by someone other than the maker. They contain notes, material specifications, and dimensions to represent as objectively as possible the object in 2D form.

One of Da Vinci’s most important invention would be his graphic representation system, which is the predecessor to today’s technical drawing activity :

> Da Vinci, again, represented his work as drawings with accompanying explanatory text. He also experimented to find the best way to present his designs using sections, transparency, perspective views, and explosion views. Most of his methods are used today when creating technical drawings. Da Vinci also mentioned how the machines are to be used in side notes, and assigned letters to different mechanical parts, recalling them later in the text to explain their functioning.

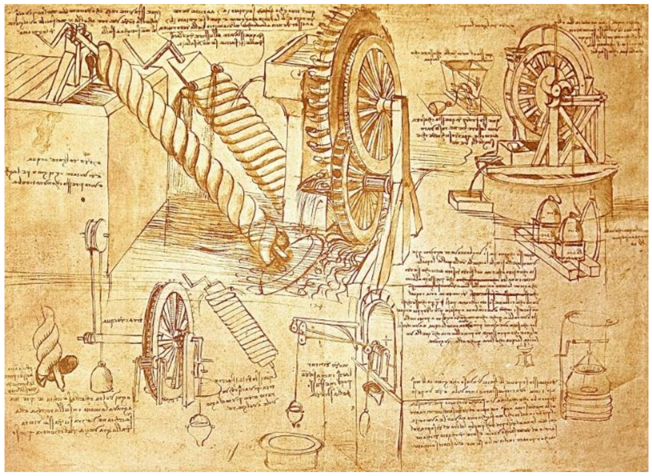


Figure : (1)

It is important to note that more than five hundred years later, those designs are brought to life in an exhibition dedicated to him. Even if the drawings weren't functional, they were descriptive and accurate enough to allow the creations to come to life when the means were available. Many of his prototypes are available at the exhibition space dedicated to him next to the Duomo di Milano. [XII]

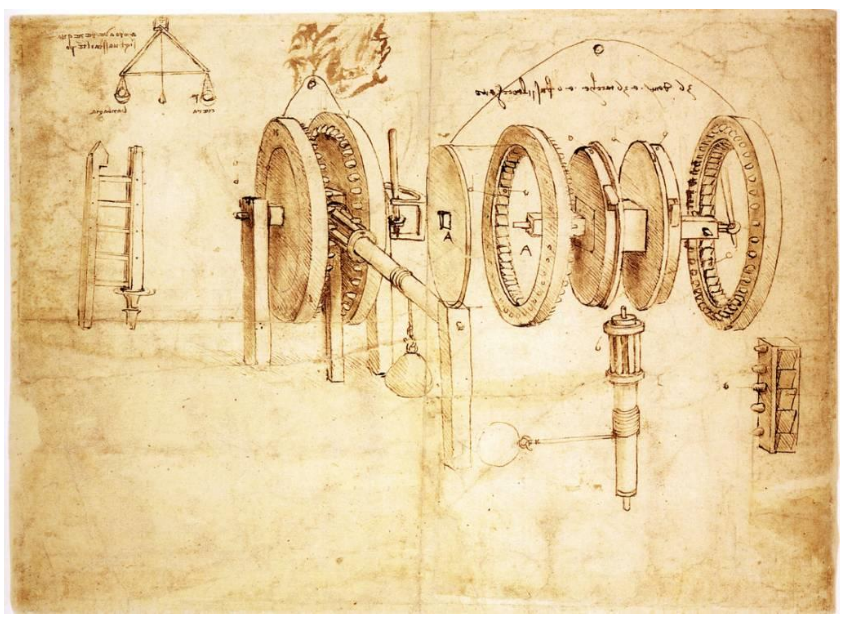


Figure : (2)

2. CAD

Computer-Aided Design (CAD) was invented by the US Air Force when in war with Korea, employing NC and CNC machines. It was meant to create a code providing a list of commands to obtain a final 2D output. It was later improved by Dassault Systemes who invented CATIA. The programs are vector based (they use points, lines and curves instead of pixels).

CAD shift a methodology in making from trial and error to repetition.

CAD also facilitates the creation of a variety of outputs and an easier assembly. It allows for more mass production (thanks to the uniformity it provides), but also mass customization since all variables can be modified. [VIII]

It later became a design and rendering step of the digital fabrication process (2D or 3D) when it was merged with CAM, simulating the path of the tool. The output of CAM is another computer language "G-Code" directing the tool in terms of length of lines, depth of surface, and the speed of its movement. [V]

CAD would allow thinking and drawing. When combined with CAM, the designer is also in control of the making, so the designer is in charge of the product not just as an object but also as a process. [VIII]

Some would argue that the CAD/CAE technologies allow to shift so seamlessly between designing and testing that the distinction between design and prototyping becomes blurred. [I] (Stuart Brown, chapter 9). This opinion obviously reflects an engineer's point of view where prototyping is not part of the design process.

3. Rapid Prototyping

Started at the beginning of the 20th century, when Sir Robert- Watson-Watt made a prototype showing that radio waves can empower an air defense system. [1]

Since the market in a user-centered us very competitive, companies have to deliver products faster, and thus shorten the product development cycle.
One efficient way to achieve this goal is minimizing time and resources by introducing small changes to the product development process lie rapid prototyping.

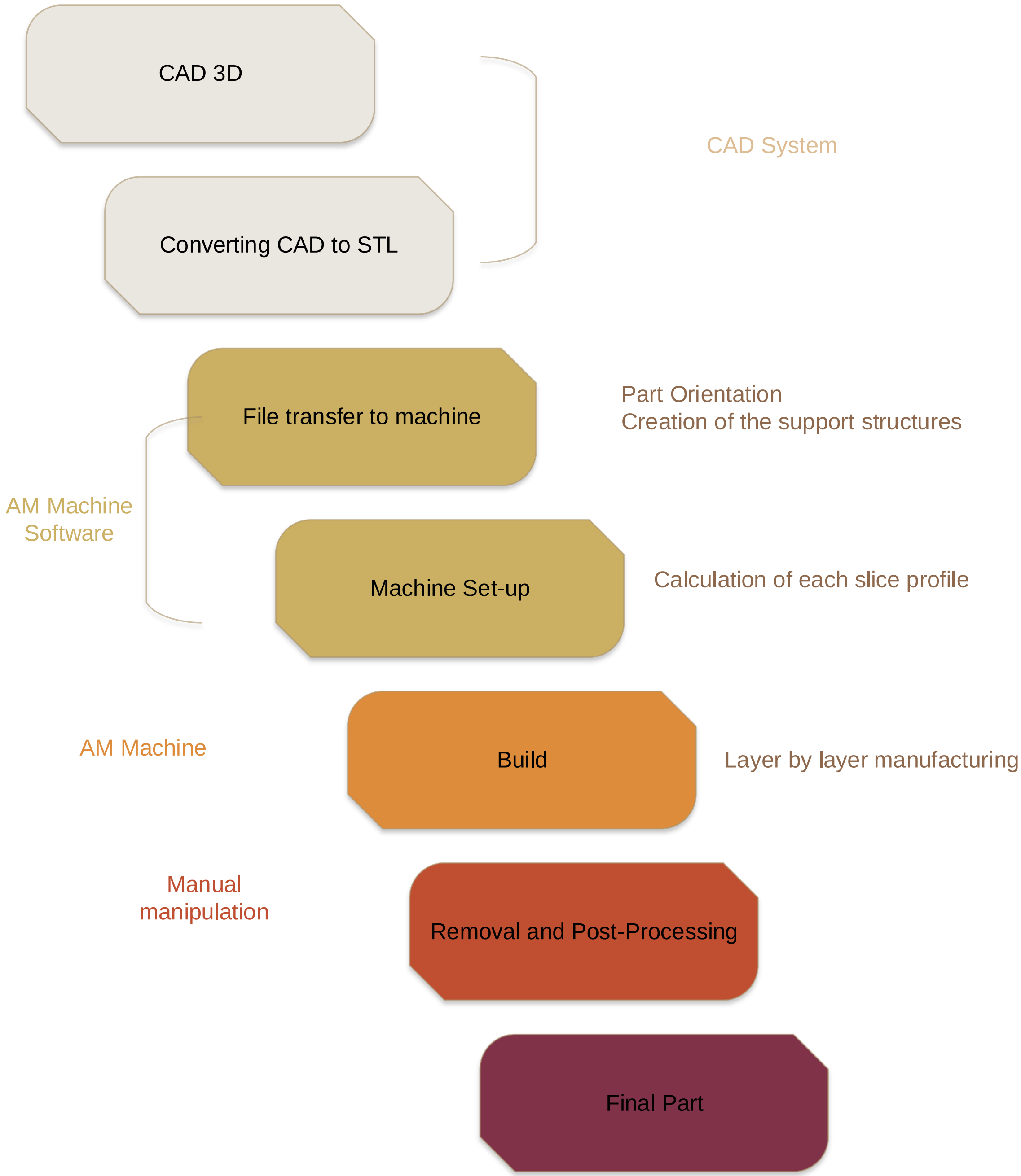
In 1980s. 3d mapping in CAD allowed rapid prototyping and parametric design to assist design production of objects from the computer to the prototyping shop. [V]

4. Additive Manufacturing

The process chain is fast, flexible and direct. The parts are created from 3D CAD data without needing the intermediate stages like tool manufacturing

1. Cad
2. Stl conversion
3. File transfer to machine
4. Machine setup
5. Build
6. Remove
7. Post-process
8. Application

The process can be either single-step or multi-step. The single-step has the part fabricated in a single operation with the material properties of the intended product achieved. In multi-step, post-processing is required to enhance the part's material properties, using infiltration, sintering, thermal or chemical modification,…



5. 3D printing

6. Virtual Prototyping

Virtual Reality (VR) is an artificial environment that is experienced through sensory stimuli, such as sights and sounds, provided by a computer accompanied by technologies, and in which one's actions can determine what happens in the environment.

A virtual prototype is a computer simulation of a physical product. Virtual reality techniques have been spreading fast in the last decade, transforming into virtual what has been traditionally real.

This tool is very powerful to gain user insights early in the design process.
It is also highly used as a tool in the evaluation step of the NPD process.

Virtual prototyping allows testing product models before building them physically. The most important aspects to study are usually the aesthetics, functions and ergonomics of the product. These are usually attributed to CAD and other softwares that can test and modify the product's properties depending on the CAD and CAE platform used, like Solidworks, Ansys,…
What virtual prototyping adds is an experience aspect, where the prototype is inserted in a situation with the main purpose to :

- Gain understanding of users and their experiences in a real/realistic world context
- Evaluate world context

Benefits :

- Reduced need for physical prototypes, saving tie and reducing costs
- Integration of measurement technology, where user's performance and impressions are studied.
- Re-use possibility of Virtual prototyping components, reducing its implementation costs and complexity
- Many variants may be tested, improving the final product quality

Virtual reality can be non-immersive, immersive or interactive.

Immersive virtual reality technology concerns mostly head mounted displays.
Head-mounted displays are devices worn by the user. The glasses contain LCD or OLED technologies and a combination of refractive lenses or mirrors that may be used to enlarge image displayed on the screen. They offer 360deg immersion for the user with a very high resolution. They are also connected to tracking devices to change the displayed image depending on the user's position.

https://makhanmalai.co/makhan-malai-oculus-working-on-immersive-theater-viewers-will-engage-with-actors-in-virtual-fact/
https://www.timeshighereducation.com/news/scepticism-over-google-plan-replace-labs-virtual-reality

Larger volumes of display that allow a greater freedom of movement are non-immersive. They can be monitor-based or projector-based.

Monitor-based large volume displays can use active or passive glasses.

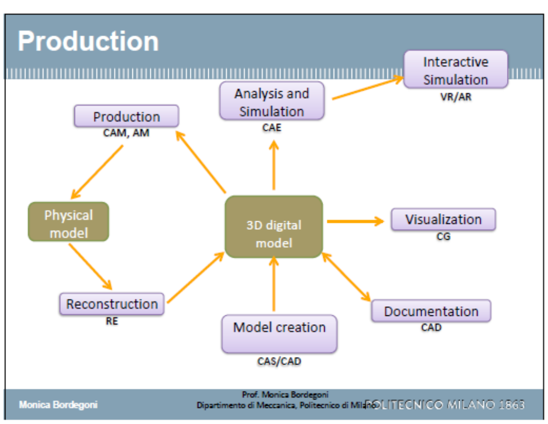
Some examples include tiled monitor-based displays like NexCAVE

https://www.ocls.info/rooms-studios/melrose-center/driving-simulator

Projector-based large volume displays include workbench displays, wall displays and cave displays. Wall displays have an output of a very big size, allowing multiple users

http://www.visbox.com/products/cave/

The use integrated in the NPD :



Augmented Reality (AR) : a live direct or indirect view of a physical, real-world environment whose elements are "augmented" by computer-generated perceptual information, ideally across multiple sensory modalities, including visual, auditory, haptic, somatosensory, and olfactory.

Definition 1 : "An AR system supplements the real world with virtual (computer-generated) object that appear to coexist in the same space as the real world" [20]
Definition 2 : "Augmented reality is a technology that :

Head-mounted devices with the video see-through technology are common tools, where an augmented feature is added to the user's real field of view.

6.1 Case study : Creating a 3D printer for Mars using Virtual Reality

This case study shows how different prototyping softwares and shared assets can be used together to create a prototype experience.

This project was developed as part of the Virtual Prototyping course at Politecnico di Milano. The team was assigned to design a 3D printer to be used on Planet Mars, taking into account the different environmental challenges, and presenting the end product to the professors simulated in its environment.

Since that simulation is to occur on a planet that is inaccessible yet for man, a virtual simulation in a virtual environment seems to be satisfying enough.

The creation of the 3D printer model, with all of its parts and assembly, was done on SolidWorks. The team gathered 3D models of 3D printers found on GrabCad, an online community of professional designers, engineers and manufacturers where CAD models are shared. The parts dimensions and shapes were modified to suit the requirements of the printer to be created and reassembled into the new machine. Technical drawings of each part were made along with an exploded view and the Bill of Materials.

Solidworks does allow the designers to specify the materials, and change the outer appearance of the parts, however for a more professional look and feel of the product, KeyShot was used to select an appearance or potential appearances of different parts.

Once the 3d model of the machine was obtained, it was time to show its functioning in its use environment.
To complete the task, the team used a virtual prototyping software, Unity, very well known for its use in the Gaming industry.
Unity itself is most adequate to creating objects with defined materials and physical properties and animating them.
Along with Unity, Visual studio is used creating codes in C# language controlling the animations and relating them to stimuli like the click of a button or the end of a task.
Beside the technical possibilities that unity offers, it also has an "asset store", where users may offer their projects, models, animations and codes, in return for money or completely for free. So there is a community of prosumers and users that make using the software and its assets easier.

Finally, whatever technical issues the team faced while working on the project, some solutions were also developed by referring to Youtube videos, with amateurs, pro-amateurs and software developers suggesting solutions to common problems.

The project was presented with a video, completely simulated and animated on Unity showing how the 3D printer is to arrive, be assembled and function on planet Mars. The presentation also included a demo, in which the professor and others were shown the interface designed with the 3D printer, and were allowed to click the different buttons and check the functioning of the 3D printer themselves as if they were its intended operators.

The project was completed in two month, and this fast development was possible thanks to different factors :

- The different softwares allow integration : Solidworks' format .sldprt can be transformed to .Obj read by unity. Unity has a C# plug-in that allows the creation of codes and their use in Unity.
- The open-access sharing community, that provides tutorial and models, easing the learning process and allowing the designer to focus on the end-target instead of the technicalities.

7. Paper prototyping

Paper prototyping is used mostly in the interactive systems design. Even though interactive systems are usually experienced virtually on screens, those services are user-centered, and their early development steps rely on low-fidelity physical prototyping methods, like paper prototyping.

Paper prototyping allows more user criticism while investing in low resources.

1. The team is not completely sure of the features to be included, how to present them, and how to technically implement them.
2. The more time and resources the team invests, the harder it is to discard the idea. Prototypes should be easy to discard, change or replace
3. Prototypes that look like they didn't take much effort to be made elicit more significant constructive feedback. Prototypes that look like a sketch encourage users to talk more freely about the idea.

In user interface design, the designers want to ensure that they are solving the users' problems, and consequently, prototypes of lower fidelity are more used when testing with users, to receive at once the real criticism and refrain from investing in something that should be later modified.

How ?

type of prototype you build really depends on the questions you're

trying to address.

There's a couple of wonderful stories of this.

4. Scott Hudson,

    a researcher at Carnegie Mellon university has over the past more than a decade built a whole series of physical prototyping tools. Starting with little bits of electronics that would communicate wirelessly, have embedded power where you needed them.

    And could be pinned on to styrofoam and other cheap prototyping material, so that you could create a physical device that had interaction in it and see what it would be like cheaply and quickly.

    More recently, he's evolved that to take advantage of 3D printing. Which is often the technology that's used for creating somewhat higher fidelity but still relatively cheap prototypes of 3D devices.

5. Back of a napkin :

    prototypes on the back of a napkin with a pen or a pencil and sketch.

6. More detailed sketches :

    Sometimes what are called storyboards where you look at a series of sketches through a narrative of somebody doing something with the interface that you're looking at.

7. Wireframes are a continuing of the evolution here of getting much of the functionality and the components and the basic layout. But not all of the functionality working and all the way up to executable prototypes.

<u>When ?</u>

Paper prototypes are used when the app's main idea and features are identified. At this point, its functionality doesn’t matter much.
Concepts can be developed and tested fast.

<u>Advantages ?</u>

very cheap to implement, test and change.

Does not require coding knowledge
The core idea of the prototype is represented with no regard to subsequent details.

Enables the involvement of developers, designers, users and other stakeholders very early in the design process.

How to conduct usability testing with low – fidelity prototypes

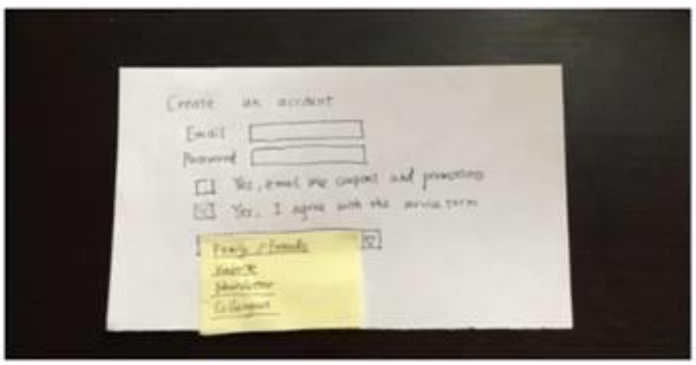
Wizard of Oz :
An experienced researcher operated the paper prototypes, simulating the behavior of the computer, while another guides the process, interacts with the user and takes notes.

Material to create a paper prototype?
paper. A pencil, an eraser, a ruler, some self-sticky notes, a pair of scissors, some transparency tape. With these tools, widgets and interactions can be simulated on paper.

Paper can simulate and imitate virtual functions. Some basics are as follows :

Text input boxes, check boxes, and radio buttons are easily simulated just using drawings on paper.

Drop down menus can be simulated by listing items on a sticky note. When the appropriate area is selected by the user, the sticky note is to be placed in that exact area.



Navigation menus are similarly simulated by showing the sticky note when the area is selected.

More complicated interactions can also be simulated using paper pull tabs.

When an item is selected, sticky notes or a drawn box can show the item is selected.

There are different ways to show expanding elements. One way is to fold the paper.

The Under construction screen and the Loading screen can be life saviors, in case an item is selected yet the designer doesn't have a screen for, or in case the designer needs time finding a screen or making modifications.

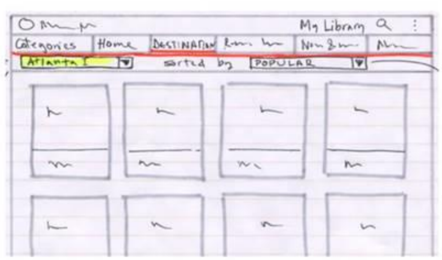
In case higher fidelities are needed, some other tools can be used.
Those can also allow to substitute the Wizard of Oz method to link parts of an image or wireframe together with hotspots.

So the user can actually click through and they'll be taken to different parts of the sketch or wire frame automatically.

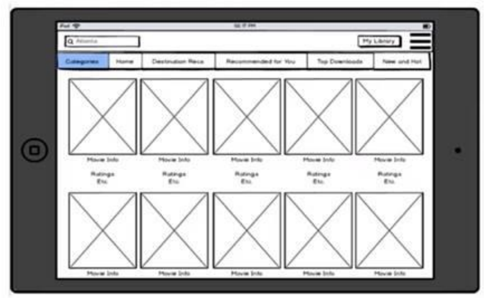
Some of these tools are :

- PowerPoint (hotspots or links between slides)
- POP app
- Balsamiq
- Pidoco
- Visio
- OmniGraffle

Paper Prototype Movie Recommender



Wireframe Movie Recommender



The images show the same screen as a paper prototype and as a wireframe. This wireframe is done in Balsamiq and is still fairly underspecified. The specific images of movies or their titles are not specified, but other different areas of the interface are. Balsamiq can link tabs to other interfaces.

An even higher fidelity can be reached using softwares like PowerPoint:

The interface looks like the real final one.

Higher fidelity prototypes can also be informative when it comes to the defined details, like what information is shown, the layout of the page, the colors used, …

It is still risky to use high-fidelity prototypes at early stages, because the user might give feedback at the wrong level, commenting on colors and fonts instead of criticizing the objective and flow of the interface. The user might also confuse the prototype for a finished product which will also affect the comments given.

A good strategy is, as mentioned before, to develop prototypes based on the type of feedback that the designer expects to gather.

A set of papers sometimes is not enough to solve all of the problems pertaining to a product, like its ergonomics, its ease of use, transportability, contextual usefulness, …. So paper prototyping can be upgraded and added to other technologies like :

- Rapid Prototyping facilities : 3D print or laser-cut your prototype

- IKEA hacking : you take an existing cheap piece of furniture from IKEA, and then you add digital components to it, in order to have the features that you want it to have.
- Lego's. They are cheaper than 3D printing, and much more readily available, and you can make almost any shape you want.
- hardware kits : basic functionality that you may want to have, so something like a button, or a light.
- Woodworking, cardboard, sewing, all these skills that you learned maybe in middle school Home EC, or even in Kindergarten, can be helpful in making devices, that's physical prototypes that somebody can interact with.

  Adding a "paper screen" to the above mentioned physical objects would lead to more accurate feedback regarding the issues mentioned.

  For example :

  Jeff Hawkins' is the creator of PalmPilot, one of the early personal digital assistants. He considered that the hardest obstacle would be the willingness to carry around a device in a defined dimension in their pocket and take it out every time they want to check their calendar. To test that, he got a block of wood, about the size that he thought a PalmPilot should be. And spent a bunch of time walking around. Every time he needed to check his calendar, he would pull out the piece of wood and tap on it to see if that felt like something he'd be willing to do.

8. Tool Example 1 (pop)

POP app (prototyping on paper app) is an app that allows the use of a paper prototype on their phone or tablet.
It is available on http://popapp.in for both Android and iPhone, and it gives the same advantages as prototyping on paper. The advantage is having somebody try out the interface on the intended device (phone or tablet), without needing a person to be the Wizard of Oz.

The images of prototypes are created by the designer on paper (The app offers nice templates that can be use to create these images). The designer then takes photos of them with the POP app. Linked areas can be marked to transition between screens. Finally, the designer can just play it, and watch a user try it out. The app also allows to give feedback.

This technology is still a bit limited, and the designer is still required to make the entire paper prototype. For now its main advantage is relieving the need of an extra researcher.

9. Tool Example 2 (Balsamiq)

Balsamiq Mockup is a wire framing tool mostly used for large scale projects like web pages. It is available at balsamiq.com.
Now, it provides a lot of the same advantages as prototyping on paper in that it takes a lot less time and you can get early feedback on your prototype. But it also has a few additional advantages, such as you don't need a person to be the Wizard of Oz. And you can actually export your prototypes into professional looking wireframes. One of the

things that Balsamiq does on purpose is that it looks kind of sketchy. If you look at it, the text looks like it's written by hand, the lines looks not quite exactly straight as if they're sketched on a piece of paper. And that's on purpose so that when you show this prototype of a sketch to a user, they know that it's not quite done yet :you want feedback that's formative rather than feedback about things like the color of the buttons.

So, the general idea with Balsamiq is :

- prototype your interface with drag and drop widgets and there's a quite a few available through Balsamiq.
- Then you link specific widgets and screens together through hotspots and
- then you watch a user try it out.

Now, final notes. Now, for this class you will have Balsamiq available but you don't really need this tool to create low fidelity prototypes. Paper, pens, pencils, scissors, all these tools that Hayi covered in her earlier lecture are really all the things you need.

However, there are some nice features that Balsamiq adds and that's why we do cover it. You can also actually achieve similar results with PowerPoint if you already have PowerPoint. But Basalmiq does make it easier to create and manage links because it's kind of made for that purpose. And the sketchiness of Balsamiq is a really nice reminder to your users that you want feedback that's more formative and that's more about your idea than it is about specific kind of graphics or characterizations of your system.

I also don't want you to think that Balsamiq is the only tool available for this purpose. There will be other tools available, newer tools for prototyping, and it's always nice to stay on top of that and see what else is available out there. But for now this may be a compelling tool for you to use.

For further exploration, paper prototypes can be combined with other forms of prototypes like virtual ones to obtain better results depending on how advanced the study has become.

9. Reverse Modelling

9.1 Case Study 5 : The use of reverse modelling to conserve and promote cultural heritage.

Visiting historical sites is a typical touristic and educational activity. Sites may be hard to be appreciated because of the amount of destruction due to natural disasters, wars, human interventions,… which is why a 3D re-construction of those sites might be beneficial for both tourists and governments.

This case study pertains to an ancient Roman Theater in Byblos Lebanon, that almost 80% of it have been destroyed through the region's unstable history.
The reconstruction was made in 3 steps :
3D computer modelling of the existing structure

1. Generating 3D point cloud of the object
2. Fitting geometric primitives to the point cloud and
3. texturing

1. Generating 3D point cloud

In general, using 3D lasers and stereo cameras are the main modes of obtaining the point clouds of a scene. However due to the high price of the equipment and the location of the site (outdoor with plenty of sun), the authors used a single camera, taking overlapping images of the same scene to estimate the 3D coordinates by triangulation. The process is known as Structure from Motion (SfM)

2. Fitting geometric primitives to the point cloud and
   The points previously obtained are to be connected to generate a three-dimensional triangle mesh approximating the geometry. This mesh is then decimated to reduce it to a manageable size, from tens of millions of
   triangles to a few thousand representative ones preserving the original topology
   and a good approximation to the original geometry.

3. texturing
   Texture maps are applied to give the geometric model a realistic visual appearance. Normal maps are also applied to control light reflections, allowing the low polygon meshes to recover the subtle details needed for realism without an increase in polygon count.

The exact number and size of meshes was managed by a built algorithm balancing trial and error to get the best image quality with the least number of polygons.

Obtaining a 3D model of the existent theatre is important. In case of further destruction or degradation of the theatre, the authorities would have a digital copy of the real theatre, which would help them reconstruct it and preserve it.

Virtual Reality

Once a 3D model of the theatre is generated, the remaining of the theater is to be reconstructed virtually using the Rhinoceros 3D software. Some research was conducted to approximate the theater's geometry and size.

Augmented Reality

Now that a 3D model of the full theater is constructed, this model is to presented to users, depending on their location and field of view.
Oculus, a Head Mounted Display device is supplemented with a tracker that can determine the user's position, and depending on his sight field, would supplement the respective image seen. This mode is completely immersive since the sun wouldn't allow other screens to be visible.
It is important to note that since it's a stereo display, each eye will have a slightly different angle from which the scene is observed. That is due to the inter-pupillary distance, responsible of allowing humans to see in 3D not in 2D.

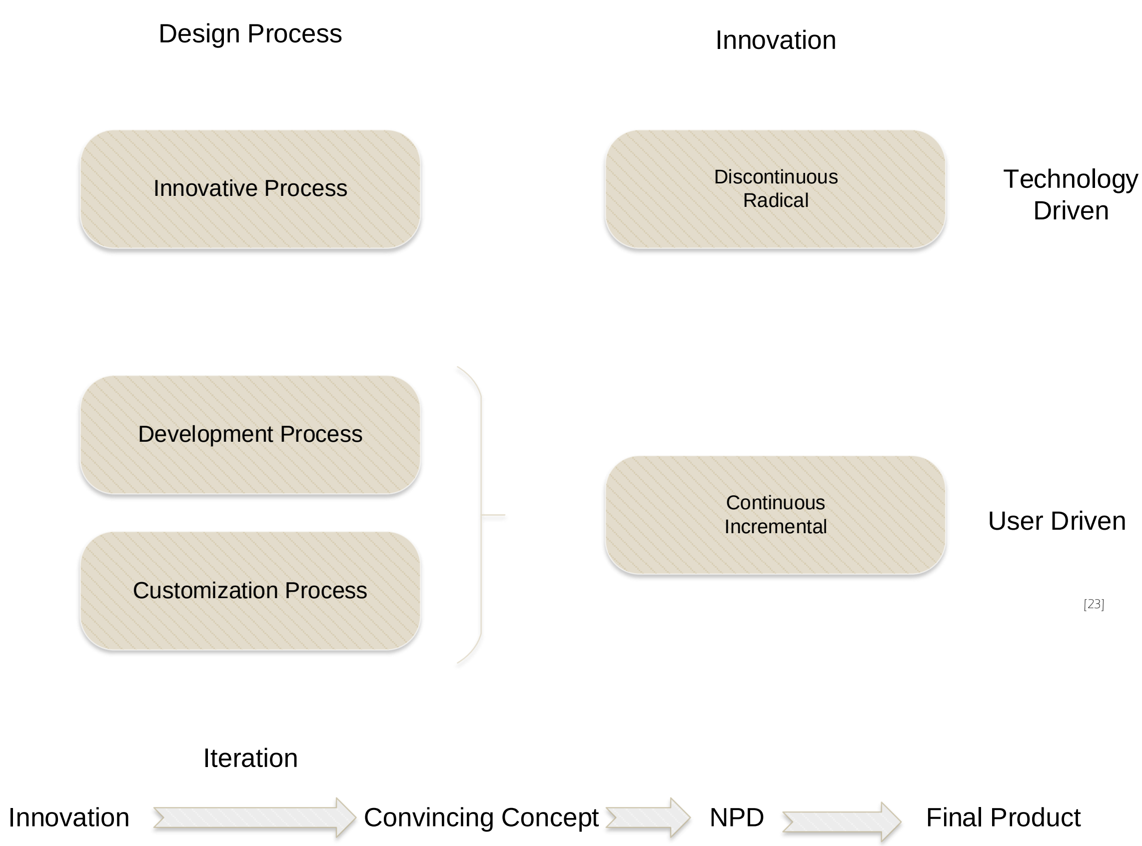
An additional step was taken, to allow the user to interact with the augmented model in a virtual setting using Unity, a game engine widely used for virtual reality applications.
The scene is reconstructed in Unity. The user can use the keyboard to change his position and discover different parts of the theater, with pop information. This method is non-immersive.

[30]

10. Engineering Softwares :

Aside from the CAD/CAE/CAM tools, some softwares allow more refined studies, in which the environment of the product can be simulated. If the product to be made is a random chair or table, the virtual environment does not sound like a necessity. But some fields do require simulations because testing in real life can be too expensive, dangerous or unethical.
For example, the aerospace field : when developing a new prototype for airplane wings, those cannot be built right away and tested with a real pilot flying them. They might be non-functional and he might risk his life.
Some softwares like Ansys, would allow a Finite Element Analysis, taking into account fluid flows and their properties, so that the product can be tested virtually and safely.
The same can be said about the biomedical field. When developping a new product, the first tests are simulated virtually while mimicking the body properties, the geometries and flows in question, since it is unethical to operate on humans. Some components of the simulation might be made in CAD, but the final simulation takes place elsewhere with other variables added to the equation.

I. The Maker's movement
II. Designing products today



III. Prototyping today

1. Problem-solving
2. Explorative
   Provotypes
   Genotypes
   Archetypes

Defining a prototype can be confusing, since the applications of prototyping are wide, and include many fields, consequently its definition might slightly alter from one source to the other.

The word “prototype” has an original Greek meaning “first example” [IX]. The definitions in dictionaries like the Oxford dictionary of the Merriam-Webster refer to prototyping as a first example. These definitions are too wide and might confuse prototypes with archetypes.

Prototypes are in general considered first preliminary models, representing materially an idea. The medium may differ depending on the purpose and the professionals involved. Designers would consider sketches and drawing as prototypes, while most engineers would only call a prototype, a version of the product that can be tested and report results.

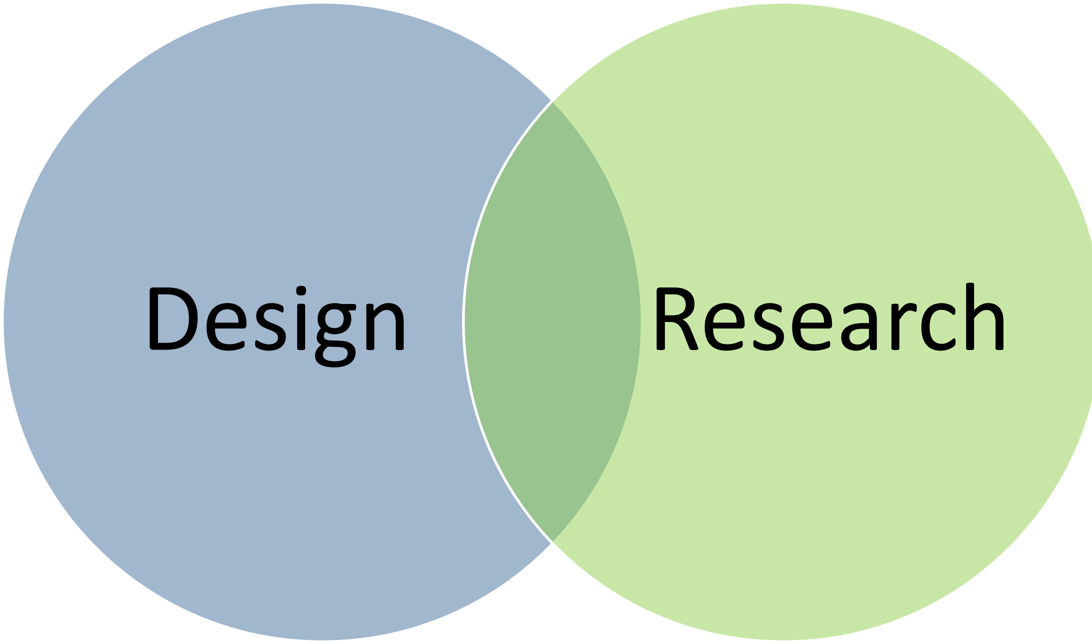
Prototypes also are not only used by designers, engineers and architects anymore. Other professions have acknowledged interest in design methods, like business companies who are interested in design strategies, or scientists who explore …. [*check papers on provotypes, lucia’s draft and Stappers what else*]

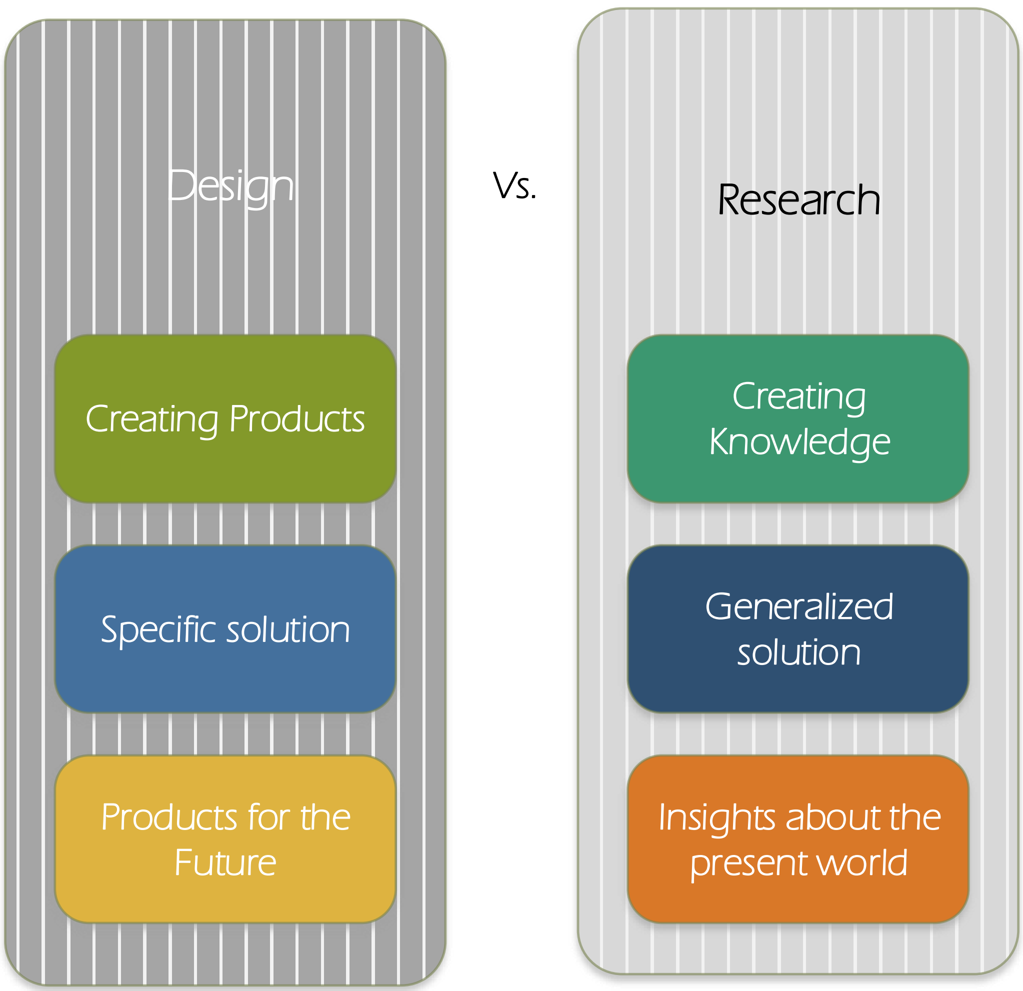
A good issue is : how to develop new systems while insuring their feasibility. This can be achieved by a series of prototypes, where those are conceived as a construction of the future, a “preliminary version of a potential product”, and then iterations, where some solutions are guessed, implemented and tested, and based on that better guesses are made. Some concrete experience is highly advised, where users can experience the product to assess its usability and usefulness as prototypes evolve.

Activity theory is another method, by which an expansion is seeked, and practitioners are attempting to find new contexts while ensuring they fit with current practices.

Some more existential issues with creating the new by exposing problems in current practice : to provoke.

Provocation aims at finding unidentified problems with current products and practices


Design
Research



As shown in the figure above, different sources may add a characteristic or another for the “first model” basic definition. As we are interested in user-centered design, we will adopt the last definition, which is a mixture of all of the above, without constraining the act of prototyping to a given professional. The “prototype” shall be called the designer, even if professionally, he has a different formation. The prototype, in this study, is “ a manifestation of an idea into a format that communicates the ideas to others or is tested with users, with the intention to improve that idea over time.” [IX]

2. The Role of prototypes

As mentioned in the previous section, the concept of prototyping can have several definitions, consequently, many roles depending on the definition adopted. A prototype, in general, would have one or multiple of these roles [III] :

1. Experimentation and Learning
   A prototype can help experiment and learn, when the designer is just tinkering around trying new things. This mostly concerns physical prototypes. This can include tinkerers and makers enjoying their time, it can include designers and engineers in R&D offices, but it also includes scientific research conducted through prototypes.

2. Testing and Proofing

It can also define the feasibility certain elements. Checking if a certain design is able to complete its intended function.

3. Communication and Interaction
   Prototypes are the common ground or common language that all professionals can share. Once a physical/virtual prototype is at hand, multiple parties can communicate and express their …

4. Synthesis and Integration
   Parts and subcomponents are brought together to check if they fit together and function according to plan. When assembling the prototype, all aspects of the design, including manufacturing and assembly issues will be addressed, so that all team members can deal with the problems once the real product is to be assembled.

5. Scheduling and markers
   A prototype marks the end of a development phase, hence it shows how fast or slow the development process is, and if the team is following the schedule.

Design is not a completely practical field anymore, since today design is taught in technical schools not only artistic ones, some designers with growing curiosity are interested in studying design from a scientific and experimental point of view. Prototypes used for scientific inquiry or discovery have exploratory roles, like experimentation and learning. These prototypes are built using the same techniques as prototypes used for user-centered design, however their purpose is different.

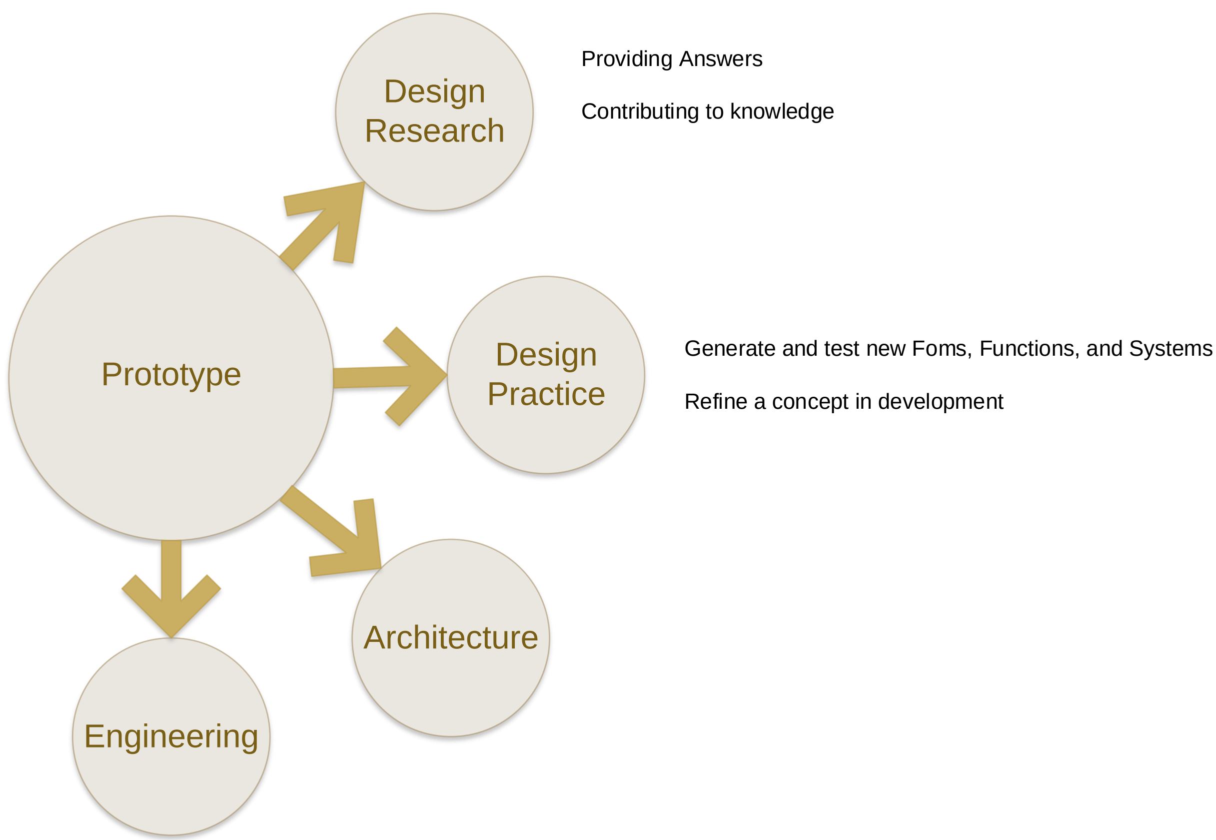


Figure 2: Design Practice and Research differences

Design research addresses open-ended questions based on design activities.

Prototypes can be used as :

a. an experimental component where its appearance, functionality or interactivity is to be tested.
b. A mean of inquiry, for example in technology probes and provotypes, where information is collected from users pertaining to a design-relevant issue
   Provotypes : Provoking prototypes. They embody tensions surrounding an area of interest. Provotyping can help both investigating and designing a new possibility. [14]
c. A research archetype, where a design is used to arise criticality. The prototype plays both an exemplary and an ostentive role.
   Research Archetypes : physical embodiments of concepts, understandings, design spaces, that can be argued to contribute to the discipline. [1]

Even the process of prototyping can be a vehicle for inquiry, since it carries tacit knowledge that is difficult to quantify.

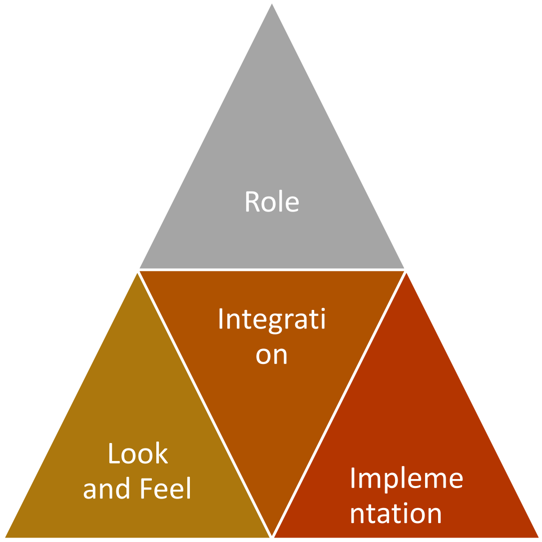
In this study, we are interested in prototypes made for design practices, and more precisely user-centered design. In this case, prototypes are used to communicate a role, a look and feel, or an implementation of an idea.

The role of the prototype must be studied to ensure that the product would be fulfilling the task he was created for. A design might be too complicated or strange for a user to understand its use or its utility. Many products are used for different purposes than the ones they were created for. In order to test the role, we must create the context in which the product is to be used.

The look and feel of a product are very important aspects. The user's first interaction with the product would be through it looks, and further its feel. If those are not appropriate : uncomfortable, unattractive, unrelatable,… the user is less likely to choose it when given different other options in the competitive market. The look and feel can be improved once the user has experienced them, and they also help give concrete sense of what the future artifact would be like. A user experience can be simulated or created for that purpose.

The implementation prototypes are used by the team to experiment and demonstrate technical feasibility for their organization, and they can also be used for feedback from users on performance issues. This kind of prototypes is one of the trickiest to deal with due to their complexity, but also due to the fact that they are seen as finalized once they function and might end up being adopted with no further refinement. For the implementation, a working system must be built to answer technical questions pertaining to the functioning of the future artifact. [7]

One prototype can have one, two, or the three roles combined, depending on what it investigates. When all three roles are incorporated in one prototype, this one will be almost identical to the final product, and is called an *Integration prototype*



These roles are explained in details with thourough examples in Houde and Hills's work *What do prototypes prototype*.

- Common problems : progress developed demonstrate feasibility but may turn out to be difficult to maintain and develop.
- The temporary user interface may not be redisgned before thre final system is relased

Who builds the prototype ?

Since Prototyping is a key problem -solving activity. The more complicated the product, the more disciplines will be involved and prototypes needed. [VII]

The product/industrial designer would conceive the product form in terms of relationship between technology and users. The form of the object however may be dictated by the engineering team if the function is too complex. [VI]

In general, the groups working directly on products include designers, Mechanical engineers and Electronics engineers.

	Role	**Look and Feel**	**Implementation**	**Integration**
Question	What role does it play?	How does it look and feel like?	How will the design be implemented?	All the mentioned questions

What is it	New functionality, New role for users	Known functionality presented differently	Known functionality based on new technique	The complete user experience of an artifact
Requirement	Requires the context of the artifact's use to be established.	Requires concrete user experience to be created.	Requires a working system to be built	All of the mentioned requirements
Managed by	Designers	Designers	Engineers	Designers and Engineers
Fidelity	Low-medium	High	Medium-High	High

Table 1 : Comparison of different prototype roles

Audiences

Figure X shows different groups involved in the making of a product. Thankfully, not all of these are involved in the prototyping stage.

Prototypes are mostly built by a team of designers and engineers, in order to be produced and offered to users. Since users' needs should be satisfied, those are the primary audience, specially that this study focuses on User-centered design.

Designers are also an audience themselves : A designer can propose his idea to a fellow designer, together they can evaluate it, discard it or develop it; the group of designers will work together finding a way to implement it, build prototypes to assess their work properly and improve it, …. Designers build low fidelity prototypes first for themselves and their team, and later furthermore refined prototypes are built for users to test.

A third important audience is the organization's management. This entity is the one financing the project, and hence makes decisions on whether a project is worth the work or not. Management can be hard to convince, specially when the product proposes radical innovation instead of incremental one.

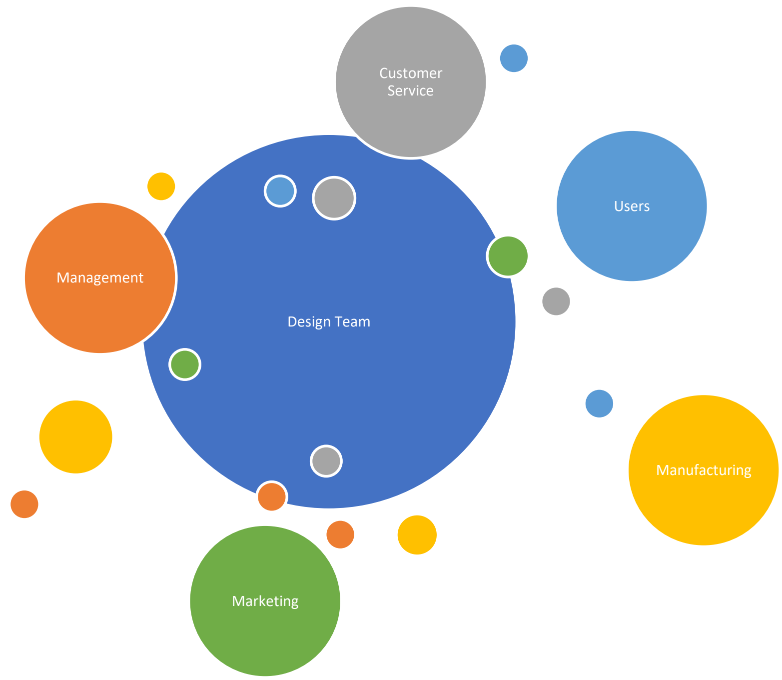


Figure X : different actors involved in the product development process

	Design Team	Organization	Users
Who?	Designers and Engineers in the studio/ laboratory	Project managers, business clients, professors, …	Unexperienced intended users of the product
Why ?	Evaluate different design directions	Indicate progress and direction	Feedback on evolving design
Role Prototype	Defining its use	Defining its use	Defining its use
Look & Feel Prototype	Concrete representation as visually finished consumer product.	Verification before committing to production tooling.	Concrete sensory experience of the artifact .
Implementation Prototype	Figuring out how it functions/is assembled	Demonstrates technical feasibility	Feedback on performance issues
Integration Prototype	made to understand the design as a whole.	Shows a close approximation to the final artifact	Feedback on the overall design

Table 2 : Prototypes' audiences and their expected feedback

3. Carrying knowledge

Passing by the Volkswagen Group Forum in one of Berlin's main streets, one might notice that a quote on its windows : "Error - the Art of Imperfection". Intrigued by this bold statement, on one of the most efficient German automotive company's window, we realized that it was part of an exhibition for Ars Electronica.
Ars Electronica is one of the world's largest media art venue for art and innovation. It organizes festivals (or exhibitions) for art, technology and society on a yearly basis. And this year's theme is this one : Error -The Art of Imperfection.

Why would reading "error" on Volkswagen's window instigate wonder ? When dealing with efficient and reliable products, one does not consider the errors that lead to the final product, yet acknowledging that this one was not ready from the first try.

Error is part of every successful procedure and product, yet it is not what designers or customers wish to deal with or hear about. Why would an Art, Technology and Innovation platform discuss Error ?
Error has always had a negative connotation. Since our childhood, our earliest school days, we were pushed to avoid error, or commit the least, because those are usually penalized. However it is through "error", the new choices we create, our deviation from the norm, that innovation and progress might happen.
Error is also linked to order, rules and norms of a place or a group. Error wouldn't exist unless there is order, since deviation only happens when a specific path is outlined. Yet rules are made to be followed and broken. [26]

This same media art platform held a different festival in 2016 with the theme "Human factor-Endless Prototyping". The prototype is an element of uncertainty and instability. The exhibitions aimed at bringing out the human factor in prototyping, how imperfect humans would create imperfect products, and how imperfect/unfinished products are a mean for humans to build and survive.
[28]

Frugal innovation can be achieved only when designers are knowledgeable about the materials, structures and manufacturing methods to innovate better and cheaper. [iv]

Prototyping and designing is in general described as a "trial-and-error" process. As mentioned in the NPD section, this process is widely used as a problem-solving tool or as an explorative tool, in either way, knowledge is to be created and shared.

Zimmerman (2003) indicates that design is a form of research, or design and research are the same because they can both lead to new knowledge.

In every design project, designers can learn something new : the users' lives, a piece of technology, a new mechanism or form, how to create an effective prototype, how to evaluate it under challenging circumstances,…

However not all design processes will lead to knowledge available to others, as many do not end up on the market.

Knowledge can be explicitly sought in some different applications, like Research through Design. It is a scientific field defined as creating knowledge through a process in which design artifacts, notably prototypes, are made, tried out, and reflected upon.
[31]

1. Research through design (Stappers)
Research and design were perceived as very distant and different disciplines, design being very practical while research is more abstract.
Design and research are being mutually used today, now that some universities and workspaces allow both to co-exist.

a. A preliminary research is made when designing new products (Research for Design)
We have observation of potential users, interviews conducted, ethnographic studies, literature reviews, measurement acquisition,…
A good designer is expected to both gather and generate knowledge. (we have machines to do the tedious tasks of copying actions like the apprentices). Here research is very specific to the end-users, and the solutions found are short-term.
b. Design is an element in generating and communicating knowledge (Research through Design)
Some prototypes can be developed to be mistaken for products and play a role generating knowledge. This can be by provoking a discussion (like in provotypes) or uncover new interactions between the user and the product.

Research through design :
Design is helping creating and communicating new knowledge (the knowledge part of a prototype)
Academic design overlaps with other disciplines like art, engineering, social sciences, …
Design does contribute to knowledge (and that is through the prototypes and the process of making them)
Prototyping "A precursor of a mass-produced product, which shares its material qualities, but will undergo testing and development during implementation."
In design research the prototype is physical, but in some areas like interaction design, it can be paper prototyping.

Knowledge is sought so it can be shared by others. The medium of sharing depends on the medium it was delivered in, like whether it is through reading and studying or through experiences

tacit knowledge : "the designing act of creating prototypes is in itself a prototype potential generator of knowledge. (if only it insights do not disappear into the prototoype, but are fed back into the disciplinary and cross-disciplinary platform that can fit these insights into the growth of theory)" - Stappers (2007)

Not all of the knowledge is grasped from prototypes, some is obtained through the interaction and skills involved.

Knowledge is also found when prototyping. Throughout the process of making, the designer gains a better feel of th materials he uses, their properties,… which procedures are best used to obtain certain results,….

4. A playful activity
5.

IV. Conclusion

We are here to discuss the importance of prototyping. It has always been a vital step in making and producing. Looking into product design and its goal of providing people with the tools they need, it is important to ensure that the purpose and the mean of doing so are achieved.

Both can be studied and improve thanks to prototyping. Physical prototyping more precisely plays a huge role in helping designers know what the customers want, and help them achieve it in the best way possible.

A historical overview shows and describes the predecessors of product designers : craftsmen, workmen, skilled laborers, …. Their activities and methods and how they improved and changed with time depending on socio-economical and technological changes.

Later, today's makers will be presented : professional product designer, amateur makers, tinkerers, … along with the different technologies that render prototyping an easier activity today than it ever was.

Prototypes are analyzed from 2 points of view : an activity connecting individuals to their humanity, but also as carriers of knowledge.

Prototypes are carriers of knowledge. Not only knowledge related to consumers and their needs, but knowledge that leads to innovation and new inventions. The knowledge is created within the prototype itself and the designer (maker) would gain this knowledge. By making more and more prototypes knowledge grows. This method is not new as it has been applied since the dawn of humanity as we know it, applying incremental change to some products, while also creating new mechanisms, technologies and meanings in others. A historical overview along with case studies show how some of today's basic knowledge was created through trial and error
The prototyping approach is one that should be natural : other than the fact that many are using it today as a recreational activity, it helps professionals from a psychological and technical point of view.

V. References

	Up until Middle Ages	Renaissance	Industrial Age	Today
Form vs Function	Form dictates function	Form is as important as function	Function dctates form	Form and function are not related
Group vs Individualism	Groups of craftsmen	Craftsmen in groups Artists individually	Groups skilled and unskilled workers	Both
Production	Linear	Network	Linear	network
Materiality	Physical prototypes and products	Physical prototypes and products	Physical prototypes and products	Immaterial prototypes and knowledge as a product
Skill	Skilled	skilled	Skilled and unskilled	Skilled (machine replaces unskilled)
Utility vs Significance	Utility	Utility and Significance	Utility	Utility and Significance

	Up until Middle Ages	Renaissance	Industrial Age	Today
Who	Cottage Industry	Guilds	Factory	Everywhere
Where	Craftsmen Only men	Scientists Craftsmen Only men Artisans	Engineer Industrial designer Skilled worker	Everyone Women included
How	Manual skilled labor	Sketches, drawings, and physical prototypes	Sketches, drawings and real prototypes	CAD Rapid Prototyping
Why	Visualize the creation in a tangible form	Test Discover Visualize creation	Functionality testing Material testing Processes testing Improvement of technology	Create knowledge Compete in the market Satisfy users Fun Innovate Create new technologies

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