VERHAERT | MASTERS IN INNOVATION

Life science innovation insights

ABOUT VERHAERT MASTERS IN INNOVATION®

Verhaert Masters in Innovation® is a leading product innovation company supporting ambitious organizations to innovate, creating new breakthrough products, businesses and services. We believe successful innovation requires an integrated approach. Therefore, we aim towards the 'sweet spot of innovation' by combining technology innovation, business innovation and design innovation. We deliver managed innovation services by integrating those disciplines throughout the process from strategy and product development towards launch. We have been doing this successfully since 1969 and have developed over 1.000 breakthrough products.

ABOUT THE PERSPECTIVES

With these perspectives we want to inspire and provide insights to innovate. Our innovation experts are looking forward to give you valuable insights on industry trends and help you fully exploit the innovation potential of your organization.

EDITORIAL

Innovation in the Life Sciences industry is under pressure, faces more competition and more hurdles to get products approved than before. This puts an emphasis on empowering the next innovation wave to shape the future. Making changes to the way we innovate, adopting new methods and techniques, looking into adjacent markets, and aiming for disruptive products and services coerces tremendous forces on the innovation departments. But I believe these changes are necessary.

Because we as mankind need to ensure the quality of life, switch to preventive care, and shift to more personalized treatments to realize this ambition for heirs. At Verhaert, we help entrepreneurs and innovation teams, who share this innovation ambition, and who are eager to professionalize the way they innovate and boost their capacity to innovate with a passion to create new radical solutions.

In this booklet, we bundled a range of topics, written by our experts, to help to create a better way to innovate whether methodologically, with best practices, or on the adoption of new technologies.

Enjoy reading, get inspired, and keep making innovation a wonderful purpose.

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Innovation insights

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The program and its publications are open to our ecosystems, customers and employees.

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Building an innovation culture

Nudge your company towards innovation greatness

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Although innovation program managers can cradle ambitious plans of a smooth-running innovation engine, reality is often that the context for change is sticky. Rather than fighting for budget and leadership buy-in, and creating frustrated innovation champions, it is better to take it one step at the time. Building an innovation culture is often mainly about change management, so let's investigate how to get everyone on board.

Understanding stakeholders

For newly appointed innovation managers, setting up initiatives across the organization can be challenging for various reasons. To avoid opening Pandora's box, they need to set expectations straight. What is often coined pejoratively as 'innovation theatre' might actually be an essential first step to rattle the cage in the organization. Not every company is ready for advanced innovation accounting and ROI optimization yet.

Innovation champions require a platform, clarity and support

Whenever you poke potential innovation champions to participate in ideation campaigns or idea development programs, it is paramount to understand that they are likely to put in the extra hours. In return they expect to gain an interesting learning experience of creativity and entrepreneurship and a platform for visibility in the company. So, whatever initiative you are launching, be clear about what will be in it for them. Even if there is no fixed process for further idea development yet. Failing to provide clarity will create frustration that generate the fastest way towards resignations by disappointed innovators.

Leadership requires manageable processes and mid-term vision

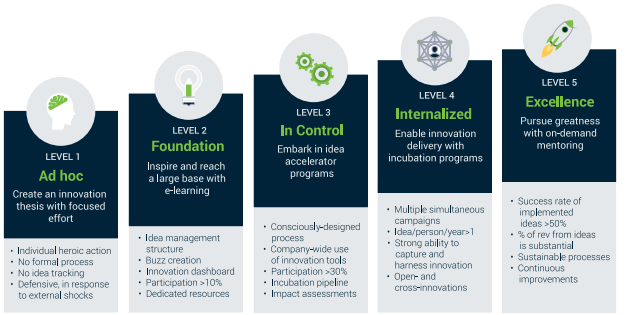
Securing endured support and budget from the leadership comes with a price. Program will be monitored in a way the management is used to, probably both in a data-driven and gut-feeling way. Align firmly about what you want to achieve, as ROI or 'innovations to the market' will rarely be feasible metrics. In lower maturity levels, it would rather be about how many colleagues were involved, participant satisfaction scores etc.

Operational management requires tangible growth opportunities

Middle management can be great enablers or blockers for your innovation program. They can endorse their workforce to participate or complain about a lack of tangible about for their business unit with upper management. So once again, be concise about what they can expect in terms of output (in year 1-2-3). Hear them out on what is keeping them up at night and how your innovation program can alleviate that. Consider also team collaboration, personal development, employer branding etc. as added value.

Five levels of innovation maturity

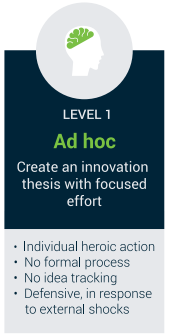
Ample innovation maturity frameworks exist online. We have adapted some of them in this visual. Hopefully it helps to navigate your position and understand how to maximize your impact at the various stages in your journey towards innovation greatness.



Innovation Maturity Model © VERHAERT

Level 1: ad hoc activities

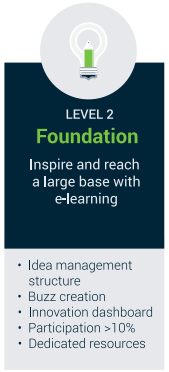
There might be an appetite for innovation, but no formal frameworks exist to support innovators although ideas might be endorsed and even executed. Budgets are typically rather limited and no program sponsor is appointed.



The initiative for the next step should probably come from a senior leader to endorse a future program and assemble a limited set of key stakeholders to draft a strategy for innovation. At the Verhaert Academy for Corporate Entrepreneurship we provide both executive workshops and individual coaching for (aspiring) innovation managers where we discuss what innovation areas should be focused on, how to nurture fuzzy ideas into development, roles and responsibilities, etc. External expertise is perhaps the best route forward to avoid blind spot from homogeneous points of view.

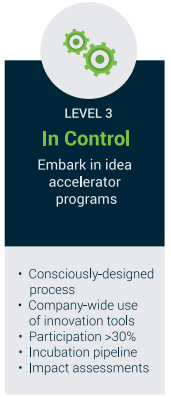
Level 2: Foundation

A certain idea management framework exists, and the organization is focussing on reaching and involving employees to embark on the innovation train. In this stage, results are not so much about ROI results yet. Just like any start-up, this is a precarious stage to be in. By providing a platform for ideation and co-creation, innovators are expecting to get inspired, be challenged intellectually and to see some ideas to reach fruition. Make sure not to get stuck too long in rattling the cage with sparkling events and campaigns. Be mindful of how to leverage your limited resources dedicated to innovation program support.



A great way to assist a large set of colleagues is to provide them with fit-for-purpose e-learning.

Our time-and-place independent learning platform works best when learning innovators have a concrete idea that require evaluation and development. Through cost-effective and scalable e-learning they are supported all the way to a validated and pitchable idea.



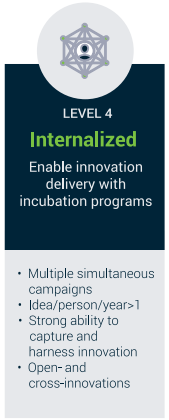
Level 3: In control

Experimental campaigns have been run, and slowly but steady the innovation toolkit and processes are trickling through the organization. There is more attention to the delivery and scaling part of promising concepts. As budgets rise, the impact of campaigns over time is measured with number of ideas that reach the market, the average time-to-market, the potential/actual ROI etc.

At this stage, resource efficiencies become important. Budgets are traded off as there are more ideas than resources to cope with. Innovators are expected to deliver a spot-on pitch during any stage gate moment. Some might not make it, so innovation managers need to be aware to mitigate this disappointment. A great way to provide intrapreneurs with a personal development experience is to onboard them in Verhaert Academy for Corporate Entrepreneurship's ready-to-go accelerator programs. In our mentor-led journey, innovators can leverage upon our e-learning library and playbooks for idea development and validation.

Level 4: Internalized

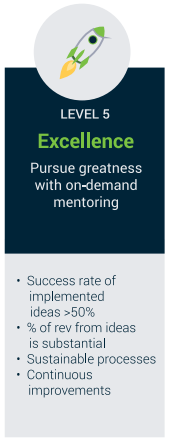
At this stage, the company's ability to capture and harness innovation gets mastered. There is a broad participation and awareness for innovation programs and innovation culture has nested in all entities. Innovation boards become more ambitious in trying to tackle transformational challenges and open innovation initiatives with start-ups, value chain or ecosystem partners. The approach is trusted to deliver results but can be optimized.



At this point, companies usually rely on our Incubation Program that guides multidisciplinary teams (including externals) to actually build the project beyond the MVP and pilot it with launching customers. Combined with our prototyping and industrialization capabilities we provide a robust engine for making it all happen.

Level 5: Excellence

In these mature stages, innovation accounting and bold vision execution are generally truly embedded in the whole organization. Striving for continuous improvement, there is again more willingness to involve externals to co-creation activities or the evaluation moments. The end-to-end process is reviewed and there is openness to challenge existing flows with new experimental approaches. After all, not every challenge type can be solved with the same toolkit and thinking frameworks.



Innovation managers and seasoned intrapreneurs are self-reliant on tools and processes but benefit from on-demand mentoring to push them for greatness in the never-ending learning journey.

Developing digital medical systems

Successful medical app development

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Successful medical app development projects clearly benefit from defining a robust architecture and a comprehensive strategic vision and framework. They also acknowledge the importance of user validation and behavioral design, even when Covid-19 is added to the challenge.

Think bigger: the importance of strategic alignment

Ideas for medical apps and connected medical devices can come from everywhere in the organization. Every concept will therefore have its own goals and context, based on where it comes from. However, digitization can transform the entire organization. Is the vision of the project ambitious enough? Is it in line with the digital strategy of the firm? Make sure that the project is aligned with the corporate strategy and that it has its spot on the innovation roadmap, to avoid unnecessary iterations or even wasted development.

For example

At a medical device manufacturer, R&D wanted the next version of a product to be controlled by an app. A project was initiated to build a basic app to connect to the device via Bluetooth. However, top management realized that such an app should be much more than a 'remote control'. The new vision imagined the app as a platform to interact with users, support them in managing their illness, serve as a sales and marketing tool and enable a future in which the generated data is processed by AI to provide new insights, supporting users in improving their lives. In this case, the initial project (which was put on hold) can probably still be integrated. But it made very clear that innovation requires an open mind and a strategic view of what a new and potentially disruptive technology can mean for the future of the organization.

The architecture challenge

Developing an app is one thing. Building a reliable, secure and scalable system and integrating it in the existing IT infrastructure is another. As soon as the concept of a medical app becomes clear, make sure to involve a system architect and members from the IT organization to ensure that the system architecture is solid and compliant with data protection regulations as well as the organization's IT policies. Be sure to have enough access to and visibility of the existing IT infrastructure (and how the organization envisions it in the future) and design the solution accordingly. Work visually to ensure that the project is clear to all parties involved and everyone knows their role. Again, this avoids the need for endless bug fixing in all layers of the system, redeveloping APIs or unplanned migrations in a later phase.

The importance of user validation

One of the most deceitful and overused words in innovation is "MVP". Of course, the idea of a small and cheap development that can be launched quickly, is attractive. The ability to redesign or abandon it based on real user feedback, is valuable. But MVP doesn't mean cheap, especially not in medical development.

In smaller apps, features and UI can be designed, based on the experience of the developer and project team. You can then observe and respond. Large organizations will include user research and user validation during development, to increase the chance of success and avoid bad publicity, e.g. early validation techniques, like interactive mock-ups to start observing and identifying social and emotional needs of the user.

In medical development, user validation (as part of Human Factors Engineering) is obligatory! It hence must also be budgeted and planned. So start with the contextual inquiry, move up to the formative evaluation of your wireframe or mock-up. And do plan for a structured way to the summative verification.

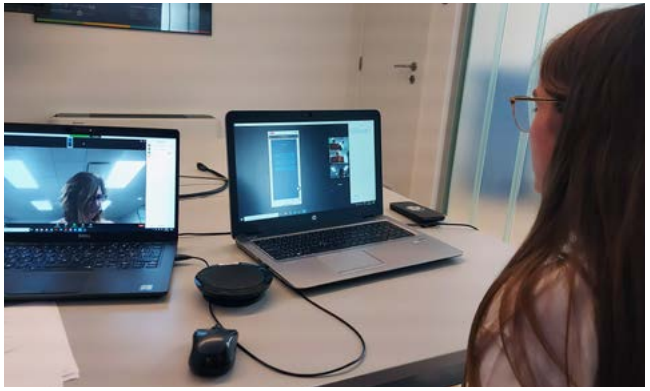
Useability studies during Covid-19

During summer, a formative evaluation study was planned to capture feedback on the designs. The design was created by Verhaert's DesignLab, DigitalLab and the client team, and

CONTEXTUAL INQUIRY	FORMATIVE EVALUATION (empirical)	SUMMATIVE EVALUATION (verification)
Stakeholder analysis	F.E. plan definition (with objectives)	User group profiling
Use environment analysis	User group profiling	Summative evaluation protocol
Job-to-be-done analysis	Formative evaluation protocol	Respondent acquisition (15-20)
(Critical) task + risk analysis	Respondent acquisition (5-8)	Preparation of test material
Anthropometric analysis	Preparation of test material	Simulation of use scenario
Use scenario analysis	Simulation of use scenario	Regulatory guidance
User needs analysis	Regulatory guidance	Usability test
Behavior analysis	Field expert review	Data processing & analysis
Cultural analysis	Usability test (+ dry-run)	
	Data processing & analysis	

translated into an interactive mock-up. Normally, such evaluation is done in person: the user/patient is provided with a device running the mock-up, while a duo of designers asks questions and observes the user as he/she navigates through the functions of the app. As this had become impossible due to Covid-19 travel restrictions, for the first time the team relied on a specifically combined set of remote tools (for calling, creating interactions, observing, capturing screen interaction etc.) for this delicate work. Although there were some concerns on capturing subtle clues and spotting misuse (e.g. a finger that searches for the right button), the team was able to adapt and get valuable insights out of the exercise with a comparable level of detail.

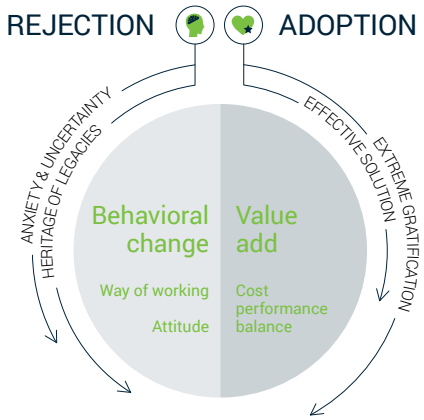
Overcoming rejection & stimulating adoption through behavioral design



Medical apps are a sensitive and personal matter. New approaches to support patients using mHealth applications can face rejection by the user group they're trying to help. What do you need to do to stimulate app adoption?

In any case, some resistance is good, because it proves that you're offering something new. The key to the adoption of your innovation is finding and understanding the type of resistance. Most people embrace innovation, but dislike and avoid changes in their habits. By identifying the sources of rejection, features can be added, discarded or adapted to accommodate these explicit or hidden behavioral drivers.

Our consulting in medical app development showed that features that increase adoption of usage and a structured way to consistently improve usability and convenience during the development are worth management attention, as they make a significant difference to the success of the app in the market.



User adoption and rejection model © VERHAERT

> I tested an app to keep a diary, but once in a while I got pop-ups on my phone telling me I was X amount of days without an attack. This is enormously irritating.

For example

Solution providers are often focused on technological solutions: ways to improve patients' lives through more features and provide them with more data. But during a contextual inquiry study for a connected device and app, in which a benchmark of current apps was discussed with patients, a significant group clearly indicated they didn't want to be engaged more.

They already were reminded of their illness enough and would never be interested in more possibilities and information. For them, all effort investment in more features would have been lost or would increase rejection. The message was to clearly focus on the most intuitive and efficient use of the system, to help them think about their illness less.

Design effective technological solutions

7 crucial tips to connect your device to an online platform

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Nowadays everything is (inter)connected, from your smartphone to your smart home or industrial device. Somehow it's all connected to the internet. If not, it's just a matter of time before it will be. In the last 5 years, we've noticed the number of IoT projects has become more standard than exception. Devices connected to an online platform have many benefits, think about collecting user insights and offering additional services. A challenge for the developers to design effective technological solutions. From applying a design thinking strategy to making smart decisions in the development of IoT devices, here are 7 action points to add to your checklist when you consider building another successful platform with connected products.

> Data really powers everything that we do.
>
> JEFF WEINER

1. What do you want to measure & why?

Collecting a lot of data and feeding it into a data lake without knowing what it is you want to do, is just a cost without any return in sight.

Every project starts with the use case. Think about what it is you want to improve, change or reduce.

- Do I need to reduce the losses in raw materials by improving quality control?
- Do I want to reduce the total cost by increasing efficiency in manpower in the production process?
- Do I want to know upfront when a machine part will fail so I can send the right replacement beforehand?
- Do I want to learn more about my product in the field to improve the next generation?
- Do I want to guarantee the quality of my product in the field thanks to thresholds you want to monitor so you can better support your customer?
- Do you want to reduce the number of calls to the support department?
- …

The use cases are endless, but don't start a project without one!

2. What is the environment your device is in?

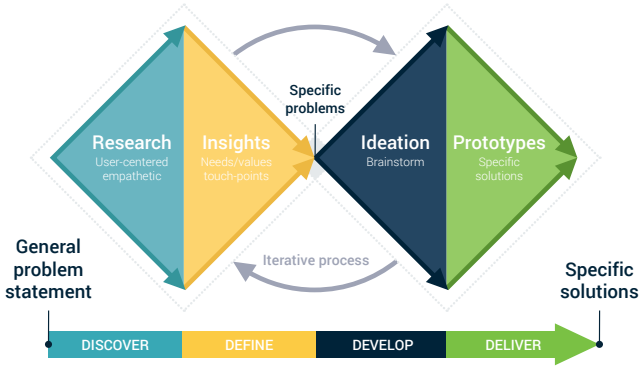
The above-mentioned examples of use cases will most definitely explain more about the environments you want to measure. You also need to consider the conditions your device is exposed to (i.e. extreme cold or heat, fluids (hot or cold), speed, vibration, etc.). In other words, can your sensor resist these possibly extreme conditions?

Also, your users' behavior is something to bear in mind when setting up and configuring your product. These actions can also be seen as 'the environment of your device'. Involving your users as early as possible will help you get the interface just right thanks to the priceless feedback.

3. Ideation, ideation, ideation & iteration

Before even thinking about the setup of your architecture or the provisioning (authentication and authorization) of your devices, you'll want to mitigate the risks of your project in a few ideation exercises. Iterate as much as necessary before designing your final product or architecture.

In an ideation phase, you want to handle some specific topics (and most probably not all in one session of course). You need to talk to the stakeholders involved and think about the technology you'll need, the validation processes you want to set up, the costing structure of your architecture, the measurement tools, the onboarding process, the embedded software of your device, etc. All with the same purpose of (re)designing your final product/ setup.



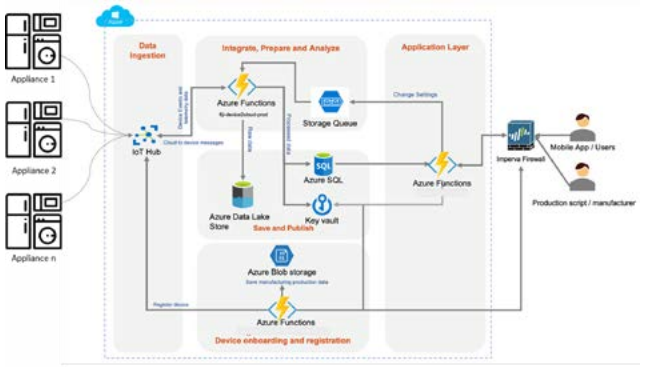
Double diamond design process (adapted from Service Design Vancouver) © VERHAERT

Once you've defined the IoT project derived from the use cases, you'll probably need to scout the available technological solutions to capture all the data you want. A proof of concept is the perfect way to validate if the foreseen technological solution will work.

Often in those exercises, we noticed you need some (technical) expertise you don't have access to in the company. Don't limit yourself to the available resources in-house. You always need to explore the competences and added value of your co-creation partners. In a project where you want to connect and monitor hardware devices, you'll need experts who master the security of your architecture, as well as the architecture itself, bearing in mind the costing model and/or business model of the project. On top of that, you'll need expertise in electronics for the development of your hardware and UX/UI experts to cover the GUIs (Graphical User Interfaces) of the solution. As mentioned before, the importance of validation with user groups (internal and external customers of your product) is priceless and essential if you want your application to be used.

4. Provision your devices in a secure, scalable & redundant environment

Once you've selected your co-creation partners who enforce your team with the needed resource capacity, the architecture can be outlined. Will your appliance (in this example a fridge, microwave, or washing machine) authenticate automatically once it's connected online, and have you considered the authorization process to provision your device to the IoT architecture?



Example of an IoT architecture with appliance onboarding & registration

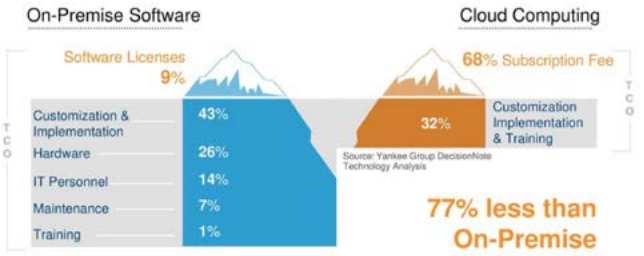
Assuming the platform will be hosted in the cloud, it's more than worthwhile to design your infrastructure as code (via tools like Terraform). Below you find an overview of the deployment process with the use of Terraform.

- **Scope** - Identify the infrastructure for your project.
- **Author** - Write the configuration for your infrastructure.
- **Initialize** - Install the plugins Terraform needs to manage the infrastructure.
- **Plan** - Preview the changes Terraform will make to match your configuration.
- **Apply** - Make the planned changes.

Source: www.terraform.com

If you're not 100% convinced of using a cloud provider (i.e. AWS, MS Azure, Google Cloud, ...), here are the main advantages lined up:

- Lower cost of maintenance (vs Employees & hardware)
- Scalability (elastic autoscaling) & availability (100% redundancy)
- Monitoring & performance visualization
- Consist
- Business continuity
- Secure
- Accountable
- Speed



Cloud lowers total cost of ownership © ADAPTIVE INSIGHTS

5. Who will use your devices & who will have access to the IoT platform?

There's a lot to tell about the GUIs of each involved stakeholder. Or what about the device data that are enriched with other online available data to feed the algorithms behind those interfaces? Depending on the use case you've defined, you should be able to define each user and/or stakeholder that will be involved in the process.

- Does my end-user connect to your device via a smartphone?
- What does the internal user need to see on his dashboard?
- Is real-time (live) data important?
- What kind of information is stored by my users?
- Is the setup GDPR compliant?
- ...

6. Measure & manage your project

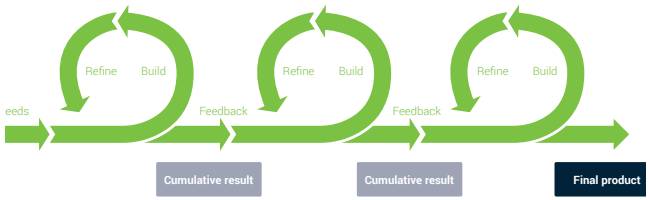
During the ideation process, you should think about the KPIs you want to set in place to measure the evolution and success of your project. It's crucial in projects like these to set the right priorities and goals with clearly defined deadlines to be met.

In most of the projects I was involved in, the real value proposition was calculated on the growth of either cost efficiency and/or revenue. Increasing the efficiency will reduce the cost (operational or production) and if you're pushing new products in the market, you should have a growth in revenue. The KPIs you set forward for your project should exactly be measuring those results.

7. Be agile & act lean

As explained above it's important to rely on experts in the field to mitigate risk. I like to use the comparison of Elon Musk and NASA to explain the advantages of an agile and lean approach. In the human quest for space exploration, NASA has proven the reliability of perfect engineering and testing will get you to the moon. Elon Musk has proven that failures in the trial and error approach will teach you a lot more and faster than having to calculate until you're 100% sure it will work.

If you can rely on the experience of your co-creation partners while learning the most in your field of expertise, your chances of success will only increase for sure. Finding the right balance between both is also an important one.



Agile & lean approach

Conclusion

Connecting your devices to an online platform is beneficial in many ways. Gaining insights on the use of your product, the user, the quality of certain parts, as well as the usage are just a few examples of the value of the Internet of Things and smart devices. As soon as the use case for your project is well established and validated with your user groups, your project can kick off bearing in mind your checklist of action points not to forget.

Innovate to be more resilient to new mutations and viruses

The role of technology in our defense against infectious diseases

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Since the end of last decade, the world has been gripped by SARS-COV-2 and its various mutations. Societies worldwide have demonstrated resilience, especially healthcare workers, scientists and all whom created the 'New Normal' that allowed us to continue our lives as good as possible. Even though it feels like the storm has passed, we need to continue to innovate. We need to innovate to lessen the burden of new waves and to be more resilient to new mutations and viruses. Innovations such as the mRNA vaccines have already made significant impact in the current pandemic, and hold an unprecedented potential to a broad range of diseases. For example through self-amplifying RNA vaccines to prolong its efficacy, or mRNA cocktails to protect against existing or predicted mutations[1]. What else could we want? Let's have a look.

Can we get rid of that painful intramuscular injection?

Or freeing up all those healthcare workers setting jabs day-in, day-out? An exciting new move is seen in the development of nasal spray vaccines delivery and drugs that may temporarily boost our resistance against viral infections[2-4]. Currently, ten nasally delivered vaccines are undergoing, or recruiting for, phase 1 clinical trials.

We're not there yet. Even though the administration is much more convenient and user friendly, with the potential of decentralizing the complete distribution of vaccines, it comes with its challenges. Unfortunately, our bodies innate immune system isn't helping, our natural defense mechanism causes some issues. One particular issue is that we actively clear the vaccines or drugs through mucociliary clearance, or snot.

[1] *www.frontiersin.org*
[2] *www.ncbi.nlm.nih.gov*
[3] *www.thelancet.com*
[4] *www.theajo.com*

Can we boost our resistance against viral infections temporarily?

What would that imply? Effectively, several studies have shown that nasally administered drugs or compounds create an additional barrier of defense reducing infectiousness of viruses drastically. These drugs may act by locally activating or 'boosting' the innate immune system, or by blocking the 'entry-points' of the virus on our cells[5 & 6]. Interestingly, in mice studies, a drug showed effective protection against SARS-CoV-2 infection pre- and post exposure, with drug administered 8 hours post exposure.

Can I boost my resistance even after a high risk event? Will I never get infected again? Hold your horses. First, let's emphasize that we're not there yet. Secondly, yes, it does seem likely that in the (near) future, we'll be able to protect ourselves prior to exposing ourselves, i.e. large indoor gatherings, and even after experiencing a high risk event, i.e. someone coughing near you.

This amazing proposition, however will only live up to its incredible potential if the temporary defense provides protection on the place of infection. This however is not trivial. It's known that viral infections spread through air in the form of small droplets, ~100um in diameter, as well as small aerosols, ~<10um in diameter. The actual spread mechanism may differ from disease to disease, also due to expression levels of receptors are varied across the respiratory system.

If we then look at the mode of administration, using nasal sprays, which typically creates small droplets in the ~60-80um diameter range, we notice a discrepancy.

[5] *www.ncbi.nlm.nih.gov*
[6] *Leyden Labs*

This may have drastic effects, as it's known that small droplets are deposited typically in the upper region of our respiratory system, whilst aerosols are deposited in the lower region of our respiratory system[7]. On top of that, it's known that different viruses have different areas of proliferation and modes of entry through receptors that may be predominantly expressed in specific areas of our respiratory system[8-9].

In other words, to live up to its full potential, innovation is required to bring new delivery methods. Such a delivery system may be required to be tuneable, to be able to target the specific regions, increase the efficacy and reduce side effects. This again, shows how technological innovations may be the key to enable the full potential of medicinal innovations.

Aside from the technical aspects, such a delivery system needs to be affordable and scalable, as it's required to be available at massive scales and herein a user-centric design is evident. We've noticed that adoption of technologies even for critical events require to be as little intrusive to a persons' behavior. It needs to be readily available, fast and agony-free. Verhaert works together with its clients to bring successful innovations to the market. In doing so in both Fast Moving Consumer Goods and Medical Devices we're experts in user-centric design, scalability and quality. In-house expertise in various drug delivery applications and spray technologies enable a broad range of innovations.

Drug delivery products are more and more seen to become smart devices, providing connectivity enables traceability and adherence features through web and phone applications, further improving the overall clinical effectiveness of the drug.

In the field of Diagnostics, aerosols have recently made a breakthrough. Did you know we can use aerosols from our breath as alternative to nasopharyngeal swabs? As a complete pain-free sampling method. Read here about Verhaerts' collaboration with Imec on the ground-breaking breath sampler, utilizing breath as a novel biopsy.

[7] *www.nature.com*
[8] *www.ncbi.nlm.nih.gov*
[9] *www.nature.com*

Develop a robotic platform

AI assisted robotic spine surgery

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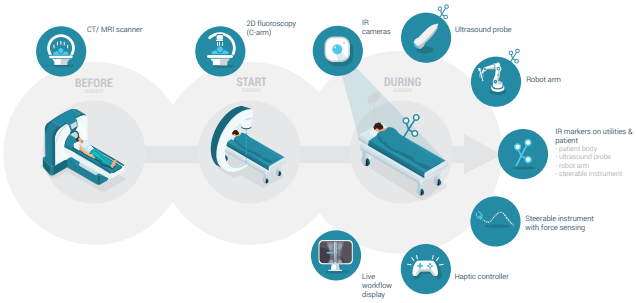
In our research project we'll develop a robotic platform for spinal surgery which uses algorithms developed by Deep Learning (AI). The developed algorithms will transform high resolution pre-operative 3D images, like CT scans and MRIs, to high resolution images of the patient in his or her new physical laying position during surgery. The novel part of the proposed procedure is the significant reduction of the use of cancerogenous ionizing x-ray beams during surgery, like CT-scans, while still being able to perform sub-millimeter surgery and catheter tracking.

3-step surgical procedure

The physical laying position of the patient changes before, at the start and during surgery, which has an impact on the **physical position and form of the spinal cord**. All these changes in position need to be taken into account in order to perform sub-mm surgery.

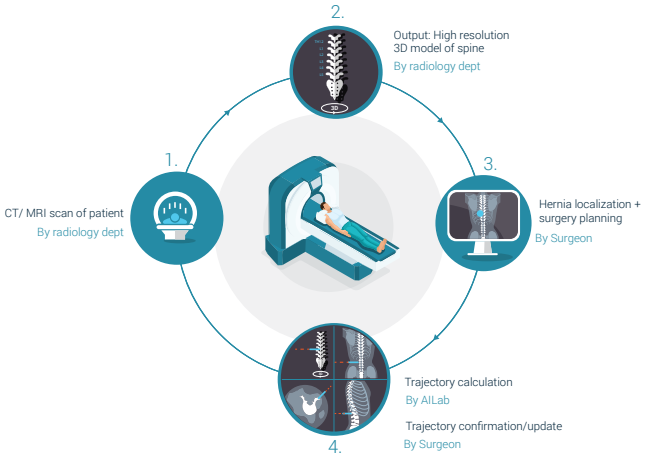
- *Before*: the patient is laying on its back for high resolution CT/MRI scans.
- *At the start*: the patient is laying on his/her stomach.
- *During*: the patient is laying on its stomach and slightly moves because of breathing, heartbeat and the impact of the surgery itself.



Overview of the patient's physical position before, at the start and during surgery © VERHAERT

Before surgery

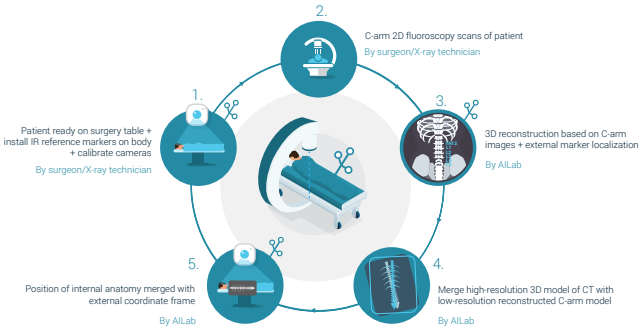
A high resolution sub millimeter 3D image is taken from the patient several days before surgery. This is done either by a **CT-scan or MRI**. Typically, the scan is taken while the **patient is laying on his/her back**. Based on the image the surgery is planned and a trajectory is calculated in order to reach the desired location in the spinal cord.



Before surgery the patient is lying on its back for high resolution CT/MRI scans © VERHAERT

At the start of surgery

At this stage the patient will be **laying on his/her stomach**. Markers are placed on the patient which are detected by a set of Infra-Red cameras in order to **create a 3D model** of the patients' physical position on the operating table. In this new position, a low dose low resolution (supra-millimeter) **2D image** is take of the **patients' spine**. The 2D image is taken with a C-arm 2D fluoroscopic scanner.

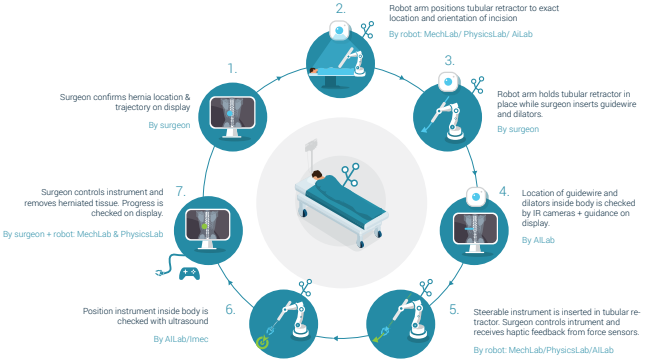


At the start of the surgery the patient is laying on his/her stomach © VERHAERT

The 2D image and the external marker localizations are used to transform the high resolution pre-surgery 3D image into a **newly reconstructed high resolution 3D image of the spine** in its new position and form. At this point, the surgeon and its team has a 3D image of the patients' anatomy in combination with an external reference frame.

During surgery

Once surgery starts, **only ultrasound images** (echoes) are used for internal imaging, which is not cancerogeneous (no ionizing radiation). The external locations of the markers on the patients' body, the ultrasound probe location as well as the location of surgical robot are detected by the IR cameras. The robot holding the catheter is then positioned to the exact location and orientation of the incision for the catheter insertion. During surgery, the **patients' spine physical position and form** will still be **subject to change** because of breathing, heartbeat and the manipulations done by the surgeon and surgery robot.



During surgery the patient is laying on its stomach and slightly moves © VERHAERT

These small changes in the spines' position and form, as well as the location of the catheter in the spine, are tracked by the ultrasound echoes. The ultrasound images are combined with the external reference frame (markers on the patients' body) and location of the robot and ultrasound scanner, all detected by the IR cameras. The ultrasound images and external reference frame are then used to continuously transform the high resolution 3D image resulting in a continues high resolution 3D image of the patients' spine and form as well as the location of the catheter inside the patient.

Deep learning & convolutional neural networks

The algorithms used for the transformation of the high resolution pre-operative 3D image will be created by deep learning (AI), more specifically through the use of CNNs (Convolutional Neural Networks).

Convolutional neural networks (CNN) are currently the major line of network structures. For different classification tasks, dedicated neural network structures have been designed that have shown to perform optimally, AlexNet was tailored to classification of 1.000 classes of objects in images and VGG, GoogLeNet and

ResNet subsequently introduced novel architecture elements and structures to improve the performance. Another interesting approach has been to introduce affine transformation into the neural network as proposed in Spatial Transformer Networks. All of these neural networks have been trained to understand the information present in pixel information stored in figures. This can serve as a baseline for our implementations.

Robotic platform

In parallel with the development of the transformation algorithms through deep learning, a hardware platform will be developed based on the current state-of-the art of:

- Body tracking systems and methods
- Surgical catheter robots
- Image guided surgical robots

The robotic platform developed in this project needs to deal with:

- Careful handling to avoid neural damage: sub N range in terms of forces
- Precise handling to avoid neural damage: sub mm range in terms of accuracy
- An ideal trajectory for the probe that can be determined in advance and corrected in real time for various reasons:
  - The spine has a different shape and position relative to the position in a pre-operative MRI
  - The patient moves because of heartbeat and breathing
- Possibility to manually overrule the robot on the basis of the surgeons' expertise and interpretation of the real time info.

Breakthrough robotic platform (guidewire based with endoscopic tip) using inverse kinematics

AI & compensation algorithms to correlate pre-operative images with catheter localisation through intraoperative images

REISS

Inventing a breakthrough AI-platform

Using artificial intelligence to track blood pressure

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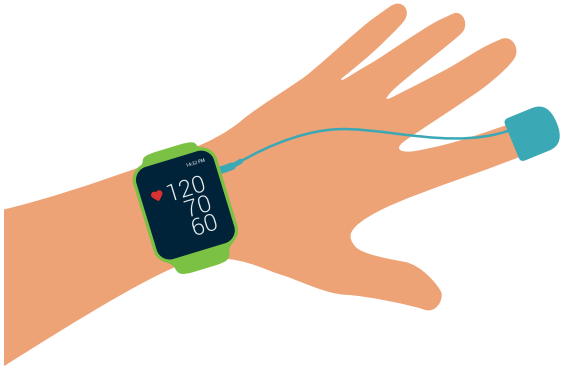
Hypertension, hypotension or irregular blood flow are linked with various diseases like coronary heart disease and ischemic as a hemorrhagic stroke. The WHO reported that around 13% of all deaths are caused by high blood pressure values. The overall prevalence of raised blood pressure (adults aged 25 and over) is around 31% (T.Mills K. et. All., 2016). Verhaert's AILab invented a breakthrough AI-platform to track continuous blood pressure from data created by a PPG-sensor (photoplethysmogram). This as an alternative of the traditional sphygmomanometer to implement in future applications.

So you can measure your blood pressure with your smartwatch?

Many people are daily tracking there blood pressure (BP). Mostly measured to get insights into their health condition or to communicate with their doctor for follow-up. **Nowadays** they measure their BP with a **sphygmomanometer**, a tool with inflatable cuffs. The main problem? It isn't a user-friendly measuring tool, also faults are easy to make due to wrong placement, and it's only a single moment measuring.

To cope with these challenges and start from an integrated product development perspective, Verhaert wanted to create an **AI-solution** that could work **with the dataset of one sensor**. This to fit into the already known applications like smartwatches, but also because it makes it a lot easier to implement in future applications.



Algorithm development to predict blood pressure by using data from a single PPG sensor © VERHAERT

Use of the PPG signal

Literature studies have shown that there exists a **relation between** the morphology of the **PPG signal and the BP**. The PPG signal is a periodically-repeated cycle measuring the blood volume changes in the blood vessels. The change in blood volume is driven by the beating of the heart. When the heart muscle contracts during systole, the BP increases, and the PPG signal shows a first peak, the systolic peak.

When the heart relaxes to fill with blood during the diastole, the BP decreases, and the PPG signal shows a second peak, the diastolic peak. The systolic peak is always clearly visible in the PPG signal and is often used to determine the heart rate. The diastolic peak is often more difficult to detect properly in the PPG signal. However, a **PPG sensor** has the potential to calculate both parts of the BP.

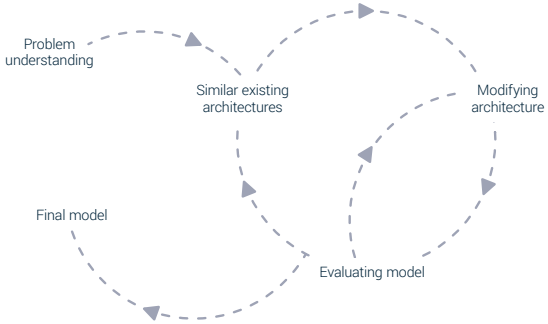
AI-solution

The algorithm that Verhaert's AILab created over the last 3 years is using "deep learning". **Deep learning** is a subpart of machine learning and Artificial Intelligence where multiple artificial neural networks are stacked on top of each other to create a deeper neural network.

We employ supervised learning which means that we need (training) data that has for each input PPG signal a corresponding blood pressure value, which is the output of the algorithm. This research is made out of **2 different datasets**. The first dataset used for training our model is the freely-available MIMIC II (Medical Information Mart of Intensive Care). After preprocessing the dataset consists of 1.862 patients. This dataset is split than into 3 groups: training, validation and testing). First a set of data is to create the algorithm. Secondly another set data is used for validation to prevent "overfitting". Overfitting is the phenomenon that the algorithm only works with the training data set. This is prevented by using the validation group as a reference, while training the algorithm. The test-group is being used after the training of the algorithm to test the performance.

In a second wave, we **trained our algorithm with a clinical dataset** that is produced in the light of this development. For this, we worked closely together with the University of Leuven and the University Hospital of Leuven. The clinical dataset is created by measuring the PPG on 3 different spots while the patients were sleeping. The intended use of this dataset is to determine how well the algorithms, created on the MIMIC II dataset, perform on new and other data. The PPG was monitored on 3 different body spots: the finger, wrist and upper arm. To make it possible to obtain proper data we used **different PPG sensors depending on the position**. There are other requirements linked to every body part. This is different in terms of LED color-wave length, reflection or transmission sensor … For every body part there are always pros and cons. The algorithm of the device has to be trained on these specific circumstances.

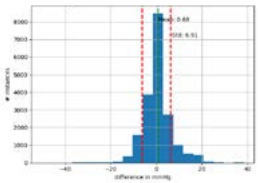
Another important factor beside is the **expected movement of the device** related to the activities of the user. These parameters have an impact on the accuracy of measuring. Parallel with creating the clinical dataset, the algorithm was developed. Every creation of new algorithms starts with problem understanding. In this case, a regression problem, because we want to predict the systolic and diastolic blood pressure. After this phase, you research the existing architectures of algorithms. This is based on the literature that



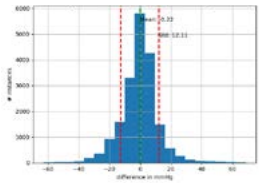
AI solution development cycle © VERHAERT

has been found on the topic or on similar topics. Remarkable is that concerning the prediction of the blood pressure given a PPG signal, the literature almost always calculates some features first, before predicting the blood pressure. This is one of the paths that has been researched in this project, but the main focus will be the **featureless approach**. The algorithm must calculate the blood pressure directly from the signal.

The **development of the algorithm** consists of multiple iterations with each iteration trying something different or tweak applied to it. The first iteration was designed to determine the optimal depth of the deep neural network to predict the systolic and diastolic blood pressure. The deep neural network has a unique block of convolutional layers that can be stacked on top of each other to create a deeper network. In the third iteration, we tried multiple different input combinations. Until the third iteration, the input to the algorithm consisted of 1 PPG signal. The third iteration tried 3 different inputs to the algorithm: the PPG signal along with its first and second derivative, 8 consecutive PPG signals in a channel-wise fashion, 8 consecutive PPG signals with its first and second derivative. As a result, we have **2 algorithms** developed: one for the **systolic** blood pressure and one for the **diastolic** blood pressure. To predict the BP there was only the need of 8 consecutive PPG segments. This way of working is unique compared with the research in the same field. We found out that this number of segments, gives accurate predictions when used to build up the algorithm.



Histogram difference true & predicted diastolic BP



Histogram difference true & predicted systolic BP

Calibration

Important to notice is the role of calibration. Because every person is physically different in many ways, **calibration can make the algorithm extra accurate**. Calibration allows for adapting the algorithm to a person's subtle differences in the morphology of its PPG signal. This accuracy is described in a system of grades. The grades usually used are those from the British Hypertension Society. The goal of this research was to get the same or higher grades compared with the current methods. Without calibration, the algorithm is capable to receive the grade A-C/D (diastolic-systolic) (It was close to grade C). If we add calibration, the algorithm is capable to receive the grade A-A/B (A or B, influenced by specific conditions). The use of calibration depends on the intended use of the application.

During the development trajectory, many aspects have been covered while implementing this algorithm. Other aspects to be considered are e.g. the computing power compared with the battery life, user ergonomics, connectivity with other devices like a smartphone … so an integrated development approach is needed to create a unique solution.

Grade	Absolute difference between standard & test device		
	≤ 5	*≤ 10*	*≤ 15*
A	*60*	*85*	*95*
B	*50*	*75*	*90*
C	*40*	*65*	*85*
D	Worse than C		
	Cumulative percentage of readings (%)		

British Hypertension Society Grading

Increasing use of technology

Why user interfaces are crucial in the success of innovation

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Trends over time have shown the importance of user friendly machine interfaces. As the information that can be shared is growing, the possibilities in digital innovation are booming. Simple user interfaces (UI) like a mechanical light switch have evolved to home automation applications or smart city solutions (Graphical User Interface or GUI), just to name two.

> A user interface (UI) is the space where interactions between humans and machines occur. The goal of this interaction is to allow effective operation and control of the machine from the human end, while the machine simultaneously feeds back information that aids the operators' decision-making process.
>
> SOURCE: WIKIPEDIA.ORG

The introduction of new tools and technologies (like internet of things, artificial intelligence or machine learning) have increased the level of complexity while the decision making based on the (nearly) live and accurate data is becoming the new standard. We want to use, monitor and manage products in ways that are self-explaining and logical. That's why the interface hides the complexity and data from the user. Gesture and voice control are nice examples of intuitive user interfaces with complex technologies and logic behind it. So how can we make sure the solutions to our needs are built in the right way, taking into account all the shared data while the complexity stays hidden?

Why is the user interface such an important part to think about when developing a digital product in your innovation of tomorrow? There are several reasons.

Increasing use of technology

Let's use “construction” as an example industry to illustrate some use cases that have led to the increasing use of technology, especially since the outbreak of the latest pandemic.

Safety has always been a well-known driver. Using drones to avoid high risk locations for workers is an obvious one, just like the use of wearables to keep track and guarantee social distancing. Of course safety regulations as well as legislation must be applied before using certain technologies, which sometimes may slow down the process.

Efficiency increase is another driver that has pushed the use of technology forward. Remote inspection of a yard to check the state of progress thanks to a web session on a smartphone or smart glasses enables the project leader to inspect more yards without the need of traveling from one site to another (or when home working has become mandatory for some colleagues).

Providing training to employees has proven to be time consuming, often without proper assessment of the improvement. Nowadays a lot of solutions help to train the worker (remote or virtual) and assist him/her on location when expert knowledge is needed at that specific moment in time.

The above mentioned use cases are only a few examples that explain why we're building more technological solutions. So, let's just summarize that drivers like **(mental) health** (short and long term), **stress reduction**, automatic and/or anonymous **alarm** systems, **complying** to all rules (big or small) as well as **control**, are the most common answers to the question why the use of technology is increasing. As technology use is rising, the magnitude of data is becoming more important and difficult to manage without the support of sophisticated systems. Building more sophisticated solutions with user interfaces also result in the growing importance of user friendly graphical user interfaces, without a doubt.

Return on Investment

Technology has often been an enabler for cost reduction with the constant pressure on gross margin (production cost and quality control). If you want to run your company efficiently, you need insights on all levels. Working closely with stakeholders in the textile industry I've noticed the pressure on margin and the need for innovation to manage more with reduced human efforts. Operating machines, planning production whilst keeping the overview of the complete machine park and order deliveries can only be achieved thanks to integrated (custom) solutions.

Nowadays everything needs to be connected to provide the right answer to the end-user, who wants to know when his order will be delivered. Looking back at the industrial revolutions, like for example the 3rd one ("automation") - as the driver for IT and computer technology - some of us remember the large manuals or often training needed to operate, control and manage the technological solutions of that time.

Comparing those automated solutions to most of today's self explanatory applications, we expect to know how to use the latter without manuals. A brief tutorial video of no more than 1 minute has become the acceptable standard and always within reach thanks to on-line streaming services like YouTube. In other words, we take the user-friendly **user interface** for granted and therefore it's the **key element** that can never be overlooked in the development of (digital) products and solutions.

The success lies in the details

You may not think much of it, but even the shape of a button can determine if a user knows how to finish a task or continue the intended flow of the application. We all follow our instinct based on visual details that have been taken into account by the software developers and UX/UI experts to mitigate the misuse of the application.

UI

Designing the **product**

UX

Designing the **experience**

Companies in charge of building your application have to ensure the continuity of use and positive spread to colleagues or friends. The user experience is key in the design of a user interface as the user wants to seamlessly navigate through the interface to make the best decisions. You want your users to recommend your tool and continue using it. Well thought and designed user interfaces increase user involvement, which creates a strong link between users and product (owners). UI design is a continuous process and one of the most important pieces of the puzzle. Communicating closely with the end-user during the research process and validating the design before development are too often forgotten. If you skip the users inquiry and involvement, you risk losing them.

> A user interface is like a joke, if you have to explain it, it's not that good!

The collection of data starts with the correct use of the interface

A lot of machine builders are customer centric. Their success relies on the operators who use their products. Over the past decades we've seen hardware providers shift from box mover to service provider. For machine builders the direct contact

and insights of the use (operators/users) of their machines has become a necessity. To improve the service towards customers, they have to listen to their users' needs (and therefore know them).

The increasing pressure on the margin in production environments has led to an even faster growing need of technology. The rise of internet of things, artificial intelligence, digital twins, connected devices, are examples that contribute to the increase of efficiency, reduction of cost, protection of that margin and the close connection with co-workers, users and customers.

Some production companies still are invisible with regards to certain stages the product is in. The real challenge is to extract the data from different sources and transform the gathered data into insights for the users, before storing it in a data warehouse. We need to make the system smart and predict where the production might fail or where in the process we can lose quality. On top of making the solution smart, we need to visualize the outcomes to make the right decision. You might be astonished to see the reduction in production cost, whilst increasing production speed and the accuracy in forecasting of production deliveries.

To conclude

Following the above mentioned argumentation we can conclude that the success of real automation and optimization relies on intuitive interfaces to operate a machine, gather and transform the data, provide the correct interpretation and visualization via the customer dashboard that holds all the information. Combined with the matching technologies under the hood, your innovation will most definitely help you reach your company goals.

We haven't seen the end of the industrial revolution, for sure! But whatever the evolution of technology, user interfaces will always have an important (if not the most important) role in innovations to come.

Connecting and creating, accelerating and improving innovation

7 key learnings about the ins & outs of the 'innovation' industry

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The innovation industry, where companies develop their new future products and services. As a manager of innovation acceleration, I'm responsible for connecting new partners to our company, and creating, accelerating and improving innovation. Together, we think about how to create a path from point A, the current situation, to point B, the future state through new product or service values. How do executive leaders try to improve innovation and bring structure in their roadmaps? Let's dive into 7 key learnings I gathered over the years.

> Minimum viable product (MVP) is a version of a product with just enough features to be used by early customers who can then provide feedback for future product development.

1. Iterations are demanding, but failing means learning
2. Don't expect to estimate budget correctly early-on
3. Remember where & why your idea originated
4. User centricity isn't new, but it's still a struggle
5. Avoid meaningless design buzz words
6. The 'minimum viable product' isn't an all-purpose solution
7. A working prototype means you're only half-way done

1. Iterations are demanding, but failing means learning

One of the basic principles of innovation is: Failing equals learning. This principle is already well-known, but it's not always easy to implement. When working on an innovation project, the best way to tackle this is to be aware that the chances of "first-time-right" are very low. If you assume you'll tackle the development without any iteration, your product is probably not innovative and you won't gain many new insights. Failing is a way to create new unique selling points, use cases and technology applications. This really allows you to become an expert in learning methods and culture, and believe me it's also really fun to have something that works out fine in the market as well!

2. Don't expect to estimate budget correctly early-on

A lot of parties want to calculate the exact price of their innovation project early-on. Out of experience, I know this is just not possible because you can't predict the future. Other than that, it's very hard to define all the specifications and requirements upfront. These unknowns influence the size and type of tasks and risks necessary to create a new valuable product or service. Another factor is that there are different ways to meet the requirements, resulting in quite different innovation and development approaches. If you want to control your budget as much as possible, try to specify the scope and include an 'innovation buffer'.

3. Remember where & how your idea originated

Everyone has a different starting point when innovating. Some detect a new market space, others find a new user need or explore how to new or existing technology applications. When developing new ideas, it's very important to understand and remember where your idea originated from. How it emerged, will determine a different context of unknowns. In many cases, you're biased. Your idea seems fantastic and successful, yet this could become your blindspot and an intrinsic danger for pitfalls. I don't want to take away your enthusiasm, of course. Try to challenge these assumptions and biases, they'll lead you to the important questions, and maybe make your solution an even bigger success.

4. User centricity isn't new but it's still a struggle

I know, user centricity is not a new design principle, but there are still a lot of struggles to convert your idea into concrete user valued requirements. This is because of two main reasons. On the one hand, a lot of companies just assume a set of requirements they think are important to users. On the other hand, pinpointing these requirements, especially the latent and hidden needs, remains a difficult job. These two aspects are influenced by the fact that a lot of innovators have already been working in the same field for a very long time. So they lose their unbiased open-minded view. How can organizations get that 'empty slate' back? A solution could be to activate other teams with no experience to review or analyse the project. However, this requires people who know the business well enough to ask the right questions yet are still impartial enough to represent consumers.

5. Avoid meaningless design buzz words

Every day, it strikes me how many design buzz words innovators use in conversations. Unfortunately, people tend to forget the real meaning behind those words and concepts because they hear them so often. Design thinking, proof of concept, disruptive ... I can go on. These are words with a real meaning, yet they're too often used without meaning. So try to look through them, what do they really want to say? Try to only use them when they really bring added value in the conversation, speed up our thinking and improve the brainstorm outcome.

6. The 'minimum viable product' isn't an all-purpose solution

The problem I want to address, is that the MVP isn't a solution for a tight development budget but a true design strategy. Of course, you'll have more budget available if you remove some of the features. Still, you need to develop the other features as well as possible to check the market potential. A lot of companies use this term because they really want to emphasize their budget restrictions and hence try to be successful with just too limited efforts. My suggestion: every innovation project has a maximum investment budget, when going above the return becomes economically unviable.

Only use the term MVP when you really want to use the strategy and its corresponding approach.

7. A working prototype means you're only half-way done

The moment a prototype works is indeed a great milestone in the development process. But often a moment to think the work is almost done. Nothing could be further from the truth. Even when your prototype is really close to the real product, a lot of different tasks still need to be executed. The next phase is what we call the production prototype phase, another detailed design phase where you'll tailor the different parts and its assembly process. In this step you'll try to meet the requirements of the manufacturing process to make it scalable and reproducible with the highest quality. In a next step, you have to build an inspection and production test approach, like including a test for incoming parts. In the life sciences industry, you also have to include validation, clinical trials, certification and CE marking. In addition, you need to ensure your production process is validated and complies with regulations. Most of the time you need double the development time.

Let's innovate together

The innovation industry is quite challenging, yet a really great market to work in. Every day you encounter challenges, and every day you find creative solutions to overcome them. Many unknown situations will pop up, creating opportunities to learn continuously. Hopefully these learnings will inspire you to create a better focus, a learning-based development plan, and most of all make you happy to go the extra mile with the team, together!

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