Tony Kuitunen

OEM Development of IoT Devices

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The software, the circuit board, and the production process require a wide range of professionals and involve several work steps. Understanding the whole and planning a careful design process before starting work will help to design products that are more complete and anticipate the stages of product development. However, a comprehensive description of the process can be difficult to find. Thus, the purpose of this thesis is to describe the whole path of device development so that a unified picture of the development and its completion about a final product can be obtained. The thesis seeks to answer questions of what should be considered when embarking on device development, how development progresses, and how people in different fields can perceive their role in the whole process.

While carrying out the study, an attempt has been made to search for reliable and generally accepted information in the international field which gives details of many processes that include creative work and experience-based opinions. This study describes development from the perspective of an IoT device, which may be part of a larger remote access and communication system.

The project has accomplished to link together the responsibilities that are important in different phases and the professions of the participating experts, finally describing an example development path. The finished work acts as guidelines at a level that allows the reader to perceive, evaluate and plan their own project and search for additional information independently.

Keywords	IoT, Interdisciplinary, smart systems, embedded, production, development, import, certification, manufacturing

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Ohjelmiston, piirilevyn sekä sen tuottamisen prosessi vaatii laajan kirjon ammattilaisia ja sisältää paljon työvaiheita. Kyseisen kokonaisuuden hahmottaminen ja huolellinen suunnitteluprosessi ennen työn aloittamista auttaa suunnittelemaan eheämpiä tuotteita ja ennakoimaan tuotekehityksen vaiheita, mutta prosessin kokonaisvaltaista kuvausta voi olla vaikea löytää.

Tämän opinnäytetyön tarkoituksena on kuvata laitekehityksen koko polku niin, että kehityksestä ja sen loppuun saattamisesta lopulliseksi tuotteeksi saadaan yhtenäinen kuva. Eri vaiheiden ja osallistuvien ammattikuntien vastuualueet nivotaan yhteen ja lopuksi seurataan esimerkkikehityspolkua, jonka tarkoitus on konkretisoida prosessi kokonaisuutena ja antaa teorialle selkeä konsepti. Opinnäytetyö pyrkii vastaamaan kysymyksiin siitä, mitä kaikkea laitekehitykseen ryhdyttäessä tulee huomioida, miten kehitys etenee ja miten eri alan ihmiset voivat hahmottaa heidän roolinsa koko prosessissa.

Opinnäytetyötä rakennettaessa on pyritty hakemaan luotettavia ja yleisesti hyväksyttyjä lähdetietoja kansainvälisellä alalla, jossa monet prosessit sisältävät luovaa työtä sekä kokemuspohjaisia mielipiteitä. Tämä työ seuraa kehitystä Internet-laitteen näkökulmasta, joka voi olla osa suurempaa etäkäyttö- ja viestintäjärjestelmää.

Valmis teos onnistuu kuvaamaan prosessit ja kehitystyöhön vaadittavat resurssit sillä tasolla, että lukijan on mahdollista hahmottaa, arvioida ja suunnitella oma projektinsa ja etsiä lisätietoa itsenäisesti tarvittaessa. Teoksen esimerkkipolku antaa kuvan siitä, miten suuressa roolissa tietyt prosessit voivat olla, ja antaa hahmotuskykyä kokonaisuuteen sekä työkalut edetä.

Avainsanat	IoT, Alkuperäisvalmistaja, älykkäät järjestelmät, sulautettu, tuotanto, tuotekehitys, maahantuonti, sertifiointi, valmistus

Contents

List of Abbreviations

IoT	Internet of Things. A system consisting of interrelated devices with unique identifiers capable of autonomously delivering information between each other.
ORM	Object-relational mapping. The set of rules for mapping objects in a programming language to records in a relational database, and vice versa.
DBMS	Database management system. Software for maintaining, querying and updating data and metadata in a database.
BOM	Bill of material. An inventory of materials, parts and components needed to manufacture a product.
PCB	Printed circuit board. Used to describe certain kinds of produced circuit boards with or without components.
CI	Continuous integration. A method of development where new features are tested and applied rapidly.
TLS	Transport Layer Security. A cryptographic protocol to secure communication in a network.
SSL	Secure Sockets Layer. An older protocol for securing communications in a network.
IP	Internet protocol address. An address for device in an internet protocol network.
RED	Radio Equipment Directive. An EU directive necessary for radio equipment to have for CE certification.
EULA	End-user license agreement. A contract between the user of software and the publisher of the software.
ToS	Terms of Service. The terms which the software user agrees to follow.

GDPR	General Data Protection Regulation. Law governing the processing of personal data in the EU.
OEM	Original Equipment Manufacturer. The original company that designs and develops the product only leaving manufacturing to third party company.

1 Introduction

The purpose of this thesis is to study the current process of bringing ideas to reality for businesses as Original Equipment Manufacturers (OEM) of Internet of Things (IoT) devices. This study focuses on IoT device development for wide commercial demand and the challenges, limitations, advantages and practical restrictions of radio devices. The communication between machines and enabling access to the end-user makes IoT devices usually more complex which requires broader problem solving than what is required in the development of a similar device that works independently. The study was carried out as a part of the development of a new IoT device for a startup company that provides rental electric scooters in Helsinki.

The objective is to clarify the process of planning and development all the way to a ready product. The thesis is targeted at professionals who work in the field and it aims to work as guidelines for planning the development of a technology production. This includes some of the best practices and work guidelines generally accepted in the field. IoT devices have naturally a broader production process due to interdisciplinary engineering aspects. To perceive the full picture means to understand several small processes that take place between planning and producing. To discuss the processes and the reality of the industry both examples and theory are introduced. The IoT industry where there is a need for a broad scope of engineering aspects such as software, hardware and process development skills is a fairly new concept. Many devices that have been analog have been made digital, and they are now are facing the challenges to be once again updated to be interconnected via the internet. This evolution has been fairly quick for some industries that have been in business for a long time before digitalization, such as automotive, television receiver and even elevator industries. [1; 2.]

The current state of the market and industry is vastly growing in multiple directions as many industries are seeing the advantages of digitalization. The technology that enables the features has taken giant leaps and investors have also been more aware of the range of possibilities that IoT devices bring to varying industries. The IoT industry is predicted to keep growing as the current IT services need to be or will be linked to IoT and as the current IT sector is growing 2 percent a year, the gap to fill the need is growing bigger. More technology is also invested in in the public sector through, for example, smart cities, e-health and smart (electric) grid movements. The growth in investments in the IoT sector is predicted to be 13.6 percent in 2022 according to IDC forecasts. [3.]

The computing power has increased 100 times bigger in IoT devices in the past 15 years, following Moore's law as the cost-efficiency of sensors has been decreasing simultaneously, making applications possible in novel situations. Increase in the variety and number of development tools has also enabled more professionals to enter the field. This has led to development kits and easier setups for embedded systems to evolve further and gain more attention. The new wave of IoT implementations is also hitting the small and medium sized businesses. McKinsey market analysis estimates that alone in Germany, which is heavily industrialized, 23 billion euros will be generated with intelligent networking of devices and machines in 2020. This is more than double than that 10 billion, which is how much was generated in 2015. The market estimates are coarse, but they do show a very uniform trend, and based on them it can be derived that the demand for IoT development is only going to go up. [4.]

2 Theoretical background

This section will introduce the theoretical background and concepts that are present at the time in the field of manufacturing and development of radio connected devices. The section focuses less on the process of software development and more on the practical challenges that need to be addressed in product development. The focus is on explaining the individual steps and tools needed during the lifecycle of developing a product. To intertwine the whole process together a proposed solution is introduced in chapter 3. This will give more clarity on how crucial the role of each step and process is.

2.1 Planning what, when and at what risk

To start with product development, this thesis will assume that the feasibility of the concept is assessed. A product has already been prototyped at the level of proof of concept and evaluated with common development tools so that it is feasible to proceed to manufacturing. These steps are made before the need for a turnkey integration is decided, before the likelihood of the success of the concept is certain and before the device can be simulated or partially made for testing. Sometimes the project does not need as thorough evaluation as the product has a readymade market or has a function to fulfill. The workflow is rarely linear but can be simplified in this text as consisting of three parts: development, manufacturing and post-manufacturing. Development consists of the design and implementation phases of software and hardware. This includes a feasibility study, proof of concept, prototyping, circuit board design, casing and software implementations. Manufacturing consists of material and supply chain planning, manufacturing specifications, testing and prototyping, samples and production orders. Post-manufacturing steps include requirement testing, certification, shipping and import necessities. Many of these processes overlap. For example, prototyping can be started quite soon during development and development can continue until manufacturing testing. Post-manufacturing processes could also be planned ahead and might not be dependent on resources from the development side. [5.]

Planning a schedule can be approached as an always-living project that evolves until the very end of the project as estimates on timeline and processes can be harsh. Sometimes timeline charts are simple enough to project how the schedule will look but most of the times a more thorough modelling is needed especially when the timeline has multiple overlapping tasks. The Gantt chart is powerful as it is effortlessly viewable and therefore it suits a project that has various professions and expertise overlapping. A model Gantt chart for a project can be seen in figure 1, which also shows how task derivatives can be assessed. [6.]

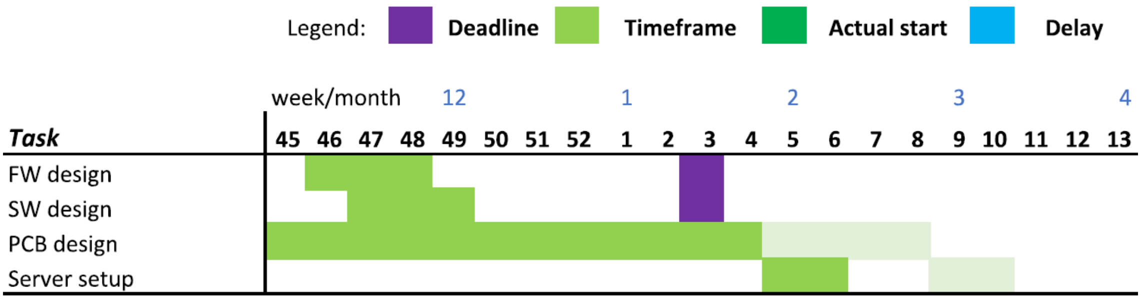


Figure 1. Gantt chart illustration of fictional processes. Modified from Gantt.com (2020) [6].

The process can involve various companies, industries, countries and personnel and as such many delays are not expected beforehand even with proper risk factoring. The risk assessment lists some estimates and possible risk factors for the timeline to be taken into account. These risk scenarios are imaginary and presented only for the purpose of demonstration. To analyze the risks a GSFC risk matrix approach can be used to evaluate scenarios that might affect the timeline in negative ways. Two factors of each scenario are evaluated and an approach on the severity of the risk and how to handle the risk is designed. A likelihood rating is given in table 1. This describes the likelihood of a risk scenario happening.

Table 1. Likelihood rating in GSFC risk. Modified from NASA (2020) [7].

Likelihood rating		
5	Very Likely	Expected to happen. Controls have minimum to no effect
4	Likely	Likely to happen. Controls have significant limitations or uncertainties.
3	Possible	Could happen. Controls exist, with some limitations or uncertainties.
2	Unlikely	Not expected to happen. Controls have minor limitations or uncertainties.
1	Highly Unlikely	Extremely remote possibility that it will happen. Strong controls in place.

Consequences rating is given in table 2. Rating is given according to how major the impact will be on schedule if it happens.

Table 2. Consequences rating. Modified from NASA (2020) [7].

Consequences	1	2	3	4	5
Schedule	Minor milestone slip	Moderate milestone slip; Schedule margin available	Project milestone slip; no impact to a critical path	Major milestone slip; impact to a critical path	Failure to meet critical milestones

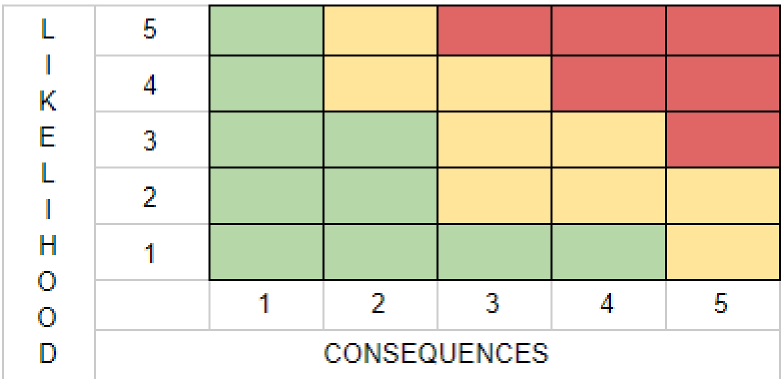
Based on these ratings, each scenario of an event will be evaluated as shown in example table 3 and then severity is determined based on the risk matrix in table 4. Each potential event is assessed individually and the appropriate actions are planned based on the severity of the risk.

Table 3. Imaginary events described. Modified from NASA (2020)[7].

Event	Likeli-hood	Conse-quences	Severity	Managing the risk
Product codebase is larger than anticipated and requires more time and resources than availa-ble.	3 Possi-ble	4 Major milestone slip; impact to a critical path	Moderate. Manage/consider alternative pro-cesses, or Ac-cept	Acceptable risk. Some features might be missing in the first release. MVP to be designed.
Non-technical issues in develop-ment will cause delays and pauses in work such as legality investigations and budget changes.	3 Possi-ble	2 Unlikely	Low Manage within normal pro-cesses, or close	A lot of pre-work is done on this and the budget is cleared for using agents and contractors for this.

The color in table 4 indicates the severity of the risk and whether the cause of the risk should be mitigated by process changes or accepted as such. The colors used in tables X and Y are explained in table 5. The event risk severity is determined by placing it in the risk matrix according to likelihood and consequences factors.

Table 4. Risk matrix describing severity of risk. Modified from NASA (2020)[7].



Risk severity rating in table 5 GSFC risk matrix describes the severity of the risk and proposes how it should be handled.

Table 5. Risk severity rating in the GSFC risk matrix. Modified from NASA (2020)[7].

Risk severity	
HIGH	Mitigate; implement new processes, charge requirements, or re-base-line
MODE-RATE	Manage/consider alternative processes, or accept
LOW	Manage within normal processes, or close

Many of the scenarios may come up during the development and even after the processes. Maintaining a risk matrix through the process keeping it updated helps to estimate and explain the situations as well as to further develop the process during and after the process. Changes in the world economy can deplete materials, and supplier sourcing teams of large production lines could try to prevent stalls in production by depleting the stocks of component suppliers, which might lead to heavy fluctuations of demand. Very unpredictable events such as strikes in a part of the supply line or quality issues that prevent the use of a batch can happen suddenly and in a more and more global economy large inventories are not necessarily kept as delivery times are considered short. This can easily mean delay of a month or two for components to reach the factory. Personal discussions with engineering offices estimate a usual time from 6 months to 12 months for the first batch of a production level design to be developed and produced. The development of code is one factor that may delay the schedule, which is / which can be dependent on various reasons that the project cannot foresee. [7.]

Using fast and productive development ideologies such as Agile development can hasten the production at early stages and clarify the scheduling early on in the development but in hardware development some things are interdependent and cannot be made in parallel. Using a backlog to keep track of the needed and wanted features and the priorities help keep the focus on the development areas that matter. It is sensible to determine at which point hardware design is fixed and software development will continue with what is available. [8]

2.2 Main expertise in the process

The development and manufacturing of an IoT product involves interdisciplinary steps where multiple professions need to communicate with each other seamlessly. For example, the development of a backend application programming interface (API) can affect the device architecture design and firmware functionality design which for one affects the hardware design of PCB and therefore the supply chain design and certification procedures as well. This means that it is fairly reasonable to presume that taking into account the interconnections before making changes leads to a more seamless development cycle.

To design the device requirements and architecture, an embedded system engineer commonly has the potential knowledge of both electronic and software implementation to the extent that prototypes can be designed. Based on these, an electronic engineer can design the schematics and finally the layout of the PCB that is to be manufactured. The connectivity, communications and edge connections, and some components such as clock crystals and external watchdogs are also designed together with a PCB designer. These can change up until the PCB design is verified in prototyping as software implementations can change the requirements. Microcontrollers have good hardware building instructions to reduce the implementation time. Some additional delays may come from complex implementations where the layout has many layers and implementing safe draws of powerlines in the PCB layout need expertise. Investing on quality can pay itself off when there are fewer iterations of prototypes and fewer hardware flaws, which are complex or impossible to patch after release.

Designing the connectivity will greatly depend on the applications that the product will see. Usually embedded or firmware developers design the IoT side implementation but cloud, server and database designers might be needed when, for example, complex or time critical protocols are implemented or bandwidth is optimized. Backend, interface and application designers are product dependent and chosen according to the needs of external services outside the scope of IoT. Determining how valuable the data is to the system can affect the need for computational power and connectivity and still affect the PCB design. Cloud computing and other uses of the cloud might make the scalability possible without limitations and thus make it possible to scale up automatically if needed, saving up work and time in the future. On the other hand, on locally implemented services this might not be needed and backend design, database and connectivity designs play a crucial role.

Non-device oriented expertise includes supplier sourcing, production planning, logistics and certification specialists as well as possible contact persons. When dealing with suppliers in countries where the business culture is very different or when there is a high risk of a language barrier, such as in China, a contact person can reduce the number of problems. Consultant companies specific for these needs exist and might provide the lowest risk of delays when dealing with suppliers abroad for the first time. [9.]

Selecting the components will greatly impact the production cost and timeline as well as the possible delivery times in the production line. The schedule for starting production can easily be postponed for months as the supplier lead times for components can greatly vary depending on the time of year, trends and the factory's suppliers. Ordering ahead is problematic as the Bill of Materials (BOM) might not be set until the final iteration of prototyping. To prevent this, many companies use sourcing specialists for supply chain management. The advantage of sourcing is to make sure that the BOM items are available, that there are multiple suppliers for them, that the pricing is competitive and that the overall supply chain risks are mitigated. Sourcing specialists usually also compete the pricing bids of manufacturing sites. The chosen manufacturing site will also affect the needed certification and the logistics needs. Some Eastern European countries such as Poland and Romania are known for cost efficient manufacturing and high quality, but commonly Asian markets such as China offer the most competitive pricing. [10.]

Manufacturing and production engineers are suited for planning the production necessities, but many PCB and electronic factories also offer these services. Manufacturing specifications are usually provided by the customer, but production line tooling, such as jigs and fixtures, which are designed to provide better consistency on quality and production speed can be implemented by the factory or third-party agents. The designed PCB will be translated to schematics, a BOM, and a Gerber file that describes the circuit board and layout of the components. [11] Factories will need additional documentation depending on their own internal processes and needed certification fulfillments. [12]

Quality assurance (QA) is a broad field that does not only involve overseeing software and hardware testing but can also make sure, for example, that the needed development tasks are fulfilled and documented in a way that supports quality, continuity and uniformity. QA specialists are used to assist in procedures and specifications of production as well as to internally and externally test the processes. A high level of quality assurance either within the staff or external service will minimize the risks before and after the product is ready.

Logistic agents are normally contacted on the site of export and third-party agents are effortlessly found. The question remains whether to use a large logistics company, such as DHL Forwarding with offices in many countries, or a small local business. With small businesses the prices might be more competitive and service more personalized but large forwarders offer reliability and ease. Freight planning is based on reservations and availability, and it is common for reserved freight dates to be postponed due to overbooking which might mean that a more important customer wants the reservation. [13] At the time of planning logistics, the certifications should be cleared and shipments should be CE marked. Certification specialists are also commonly found in third-party companies. They can ease the process of certification by preparing the needed documents for fulfilling the need, but the responsibility lies on the manufacturer, meaning in this context the company that imports the products. [14.]

2.3 Connectivity and architectural points

Edge processing or edge intelligence can help with limiting the data rates in the IoT device. Even though the bandwidth might not be an issue, the power consumption and latency can be. Processing the data before sending it will help in the long run especially if the features expand. This can even mean a physical IoT gateway that processes aggregated data from numerous endpoints via an internal network before sending the data to the cloud. A dedicated physical gateway also means there is a single public IP address that is vulnerable to attacks and preparing a secure TLS or SSL encryption becomes more efficient.

Using operating systems in embedded programming can make power consumption and real time interaction much more efficient but this is not always necessary. If the intent of the project does not require this, it might not be worth the while. The best solutions are the ones that get done. Doing things properly from the start means also to understand when scalability, user friendliness and efficiency are actually needed. Some smart devices are not smart but simple, which is a good thing. [15.]

To communicate over the internet between machines (MQTT) is widely used. Because MQTT has been a common phenomenon since 1999, it has developed into a well-suited communication protocol that has been implemented widely. It was designed to use little overhead and efficient methods between communication, meaning lower bandwidth and greater calculation efficiency but also reliance on a TCP network. This feature is favorable still even though the bandwidth of connections have risen because the demand for fast communications and data transfers in the IoT field continues to evolve as new implementations arise. In addition, the use of cloud-computing means more and less-processed data is being transferred. The best use case is usually when connections are many-to-many. MQTT is still constantly evolving and, for example, MQTT-SN is designed to help with sensor networking in the future. [16.]

An option for MQTT would be CoaP. CoaP is designed to use as little bandwidth as possible and it works as a one-to-one protocol over UPD, so transmission reliance is not the main objective to the same extent as efficiency [17]. Protocols such as HTML are widely used but not very common in IoT as they lack efficiency in embedded environments due to the architecture and also in overhead in messages [18].

2.4 Benefits of SW and HW testing

Testing the software can be outsourced. Many consultant houses provide unit testing and robot automation testing and design. Software can be implemented also from ground zero with testing in mind with test driven development practices. These practices focus on making test cases before implementing code and always implementing features against their requirements. Testing embedded code is a specialized branch in test development and can also be included in the development by the staff.

Hardware testing can be expensive to maintain and outsourcing is common. Testing the device through prototypes via functional testing but also through performance testing gives a lot of insight and is necessary before going to production. However, testing on the production line is essential because physical objects are vulnerable to manufacturing errors, environmental changes and stress caused for example by temperature, moisture, vibration and collisions. Usually the most cost-efficient way to make this kind of small-scale testing is via flying probe testing. This is where an automated machine will measure the components after production. This can be fully outsourced to the factory. The costs of flying probe tests are usually lower because these testers can take practically any board without the need for physical fixtures or jigs. Moreover, if no other automated testing is done, applying this method will at least lower the most common defects passing to the end user, which usually pays off. [19]

Functional testing also gives a lot of insight but might be slower to produce and thus more expensive to make. The most proper way to do this is a dedicated PCB tester. This is usually done with a pinbed/bed-of-nails and both functional component testings are used. The hardware used for this is very accurate and usually very expensive. PCB testers usually cost tens of thousands of euros. The technical presentations of these testing methods is later discussed in section 3 of the thesis, which addresses production.

Testing in production

In-circuit Testing (ICT) is done to specifically test the components in the PCB. This is usually done through test points, with a flying probe test or in simpler solutions through connectors. ICT tests usually consist of basic testing such as resistance, capacitance, and short and open circuits. The benefit of ICT testing is the straightforward development and implementation leading to lower cost and relatively fast production. ICT testing alone can, however, lead to functional defects passing to the end user. Wiring and microcontroller architecture defects as well as many sensor and UI defects do not show up with simple component measurements. [20]

Functional circuit testing, FCT, can be a more thorough type of in-circuit test or a separate test at the end of the production line. FCT tests the complete PCB by determining the functionalities in the circuit work. Usually this kind of testing is done with a bed-of-nails tester that connects to the PCB test points and connectors. Communication between the product and the tester verifies functionalities but can also apply the programming of microcontrollers and test the components to include even full ICT testing. If the product includes, for example, a touchscreen or a pressure sensor these can be tested with environmental testing devices, comparing the pressure of the test room or test chamber to the PCB readings or automated touch screen pushes to determine the calibration.

FCT costs are usually high due to the precision of the work and equipment. Typically, tester manufacturing costs tens of thousands and many engineering offices have teams that solely focus on tester development. Functional testing is sometimes done manually when production patches are small or irregular and some factories offer these services. Many factories do automated flying probe tests to the PCBs they manufacture. This kind of testing involves automated test needles that measure the basic quantities of the components in the PCB and many modern flying probe testers are automated to the point that they require very little manual planning. Therefore, it usually is a very cost-efficient alternative. On the downside, flying probe tests do not give as thorough insight on functional properties of the device. [19.]

JTAG interfaces on microcontrollers can be used to test the integrity of the architecture of the microcontrollers, but also to some extent the PCB's circuitry, which is called boundary scan testing. The JTAG boundary scan is used regularly to flash the program to the internal memory of the microcontroller, but historically the JTAG interface was designed to be used as a testing interface. JTAG tests can be extended to check the short and open circuits of the PCB but this is constrained to connection points. [20.]

2.5 Hardware design with radio devices on PCB

Selecting the correct components greatly influences the cost, time and production reliability. New still emerging technologies might have downsides. For example, NB-IoT and LoraWan may be more costly to produce and maintain than more widely used technologies such as telecommunication technologies and WLAN. LoraWan might need a setup of its own gateways, as is the case with WLAN. NB-IoT has access provided by teleoperators in many countries, but it is not adopted worldwide as widely as conventional technologies and no viable roaming options are expected to be available. In addition, there is no seamless mobility available, so geologically these are restricted and at best work for stationary devices. GPRS(2G), 3G(LTE), 4G and 5G allow seamless mobility, wide operation area and international mobility. Dropback possibility to a lower connection will help if a device is needed to be used in diverse places, many countries and rural places.

Modern cities might have good coverage of, for example, a 4G network but the situation might be completely different just outside the central area.

If the device needs connections abroad the chip will need to have roaming available and the SIM, whether it is embedded SIM or a physical card, will need a wide coverage operator. There are operators especially for this that sell roaming m2m sim services, such as Things Mobile, GlobalM2MSIM and Vodafone. Roaming operators may cost more than local operators as they rent the network of a local operator. Many local operators also use roaming for various reasons. As an example, the once national service provider in Finland called Telia uses roaming in their M2M SIM cards. This happens even though the network is owned by Telia itself. This is the cause of manufacturing the M2M SIM cards in a subsidiary abroad and the SIM cards using roaming to access the network in Finland. [21; 22; 23; 24.]

2.6 Consultants, MVP and post-development effects on cost-efficiency

Many of the tasks at hand might need an expertise that is not needed afterwards. For instance, the device is found suitable and necessary hardware improvements can be scheduled a year after the release in market. Even though the consultant fees are generally considered high, usually at least 90 euros per hour in the Nordics, the cost for recruiting and paying salary for underemployed personnel can increase considerably. [25]

Finding a talent might not be cheap and outsourcing to a cheaper economy country or using entry-level or student work might not always turn out cost-efficient after all. Furthermore, hiring a consultant for tasks that are considered creative, such as software development, might be time consuming. Using a consultant firm does have the disadvantage that talent and know-how does not stay with the company. There is a risk that the next time the project needs something updated, there is a new person that has to start all over again.

There is also the aspect of recruitment. Even if the project is implemented in a company that has the capability of sustaining its own team through the process, the resources are not always available. Recruiting new staff is not only slow and costly, but sometimes the needed expertise is not available in the job market. Consultant offices offer a shortcut for this and sometimes even allow recruiting the consultant.

2.7 OTA updates, edge connectors and modularity

Over the Air (OTA) updates and the possibility to update the firmware in devices over the internet makes it easier to implement new features later on especially if there are several connected devices. Updating the whole firmware is also a stepping point that might cause design changes and time delays because the transfer of new firmware usually needs at least twice the memory than the original firmware to save the new version and a bootloader application that makes the update in memory. The OTA updates which are easy to implement can be done with vast configuration interfaces that allow customization of functionality and connectivity issues. [26]

With a modular codebase, it is also possible to update entire libraries offering somewhat easy-to-implement firmware level updates. Modularity can be applied to the hardware level by constructing the device with separate blocks that work independently through interfaces. This allows more flexibility in updating and maintaining the device on another level as well as future development changes, but the disadvantage is that the system complexity gets easily higher than needed causing more work and resource needs. Updates, maintenance and debugging can be achieved also by more traditional edge connectors, thus making the development process more straightforward but in turn facing the risk of causing heavier post-development actions. [27; 28.]

2.8 Planning the certification and testing (QA) needs

Before heading to production, it is wise to revise what certifications the product needs. All electronic devices in the EU that are sold or in commercial use must comply with CE standards. In this context, a radio communication device that is coming to the EU market under CE certification has some common directives. Radio Equipment Directive (RED), Low Voltage Directive (LVD), Electromagnetic Compatibility (EMC), Machinery Directive, Restriction of Hazardous Substances (RoHS) and General Product Safety Directive (GPSD) are needed, but many manufacturers include additional certifications as well. If the device includes a battery, the IEC 62133 standard testing may apply, and if the product is to be used by under 12-year-olds, the Toy Safety Directive and testing may apply.

Depending on the application, usually at least the RED, LVD and EMC directive require testing to be done by a globally noted test laboratory. Usually RED directive testing can be obtained from the communication chip manufacturer and applied to the final product. This should be noted before applying the component in BOM as it may affect the overall process significantly. [29; 30; 31.]

2.9 The work, MVP and further development areas

When thinking about the costs, time and resources, especially when the market is waiting, there may be a need for trimming the product. Minimum Viable Product, MVP, is a concept where the risk of financial loss is minimized and the point of gathering clients is achieved faster. As a mental exercise, one can imagine that developing a car from the ground up takes a lot of effort, risks and time before a single user gets to verify the concept. Instead, if the MVP way proposes to build a bicycle, then maybe a motorcycle is built and then a car. In a project such as the one in question, this could mean using popular development kits to verify the concept such as Particle Photon, Raspberry Pi or Arduino. If, for instance, indoor positioning is something that could benefit the device, it might not be best to equip the device with kinetic positioning devices or make it a Bluetooth beacon accessible. Even the design and trial might take a huge part of the available resources and add time to the schedule. Sometimes it pays off to start with something simple, making sure it works and then moving forward.

To increase efficiency in development many companies have adopted the Agile development method. As software teams have widely adapted Agile development, the hardware development takes cautious leaps. When building a product that has a lot of software, backend and firmware, the waterfall model of planning and building hardware through tight frames and documentation step by step might hurt the overall process. Processes in hardware development can be more easily predetermined and planned ahead than in software development, but this does not mean it is always the best practice. Taking iterative development and batching up development can help the process in time and quality. This methodology can also be implemented in other processes such as QA during the product development.

When the creative environment is needed, a hardware team can also benefit greatly from Agile development. Building hardware with Continuous Integration, CI, and using automated test suites very early on in the development can benefit in finding early on what is working and what is not. This means continuous demonstrations, iterative builds, more prototyping, test-driven development and sometimes even involving the customer in the development of hardware. It might eventually mean more resources but also better quality, fewer production iterations and a more final product. Not all Agile development tools fit every project, but this does not mean they are not working, but they can have a positive impact overall. [32.]

In the Agile development, the tasks are created in the backlog during the development process, which means an easy and fast place to include and remove development options and ideas. A product owner has the primary task of maintaining the backlog and ultimately deciding the priority and structure of high-level tasks, but implementations of Agile methods vary as much as there are users. [33; 34.]

2.10 What is needed for and from prototyping and manufacturing

Because the production cost of a single PCB is lower based on the number of similar boards produced in the same patch, it is advisable to prototype the PCB before going to production patches. A hardware or an electrical engineer that designs the PCB will create a Gerber file based on the schematics. The Gerber file contains the accurate dimensions needed for the printing of the board. Together with the layout of the components, the netlist of the connections and the BOM containing the materials, a PCB is manufactured. During prototyping, the functionality of the design is assessed to make sure that, for example, the device works as expected, the dimensions meet the requirements and the components fit and work when translated to PCB.

Prototyping can be done in a different location than the production. Prototyping in a factory near the development place reduces shipping time, but prototyping can also mean testing the quality of the factory, components and the consistency of the quality. In this case, a small patch of prototypes is usually manufactured and inspected thoroughly and carefully to find flaws such as bad soldering connections or malfunctioning components. During prototyping, the cost and quality of the PCB can be optimized. The size of the surface area, number of coppered layers, materials, thickness and also the methods for soldering and finishing increase the cost. When functionality and quality is sufficient, some changes can be made for lower cost. Placement of components and redesigning the surface area can lower cost. In addition, the replacement of components with through hole soldering equivalent instead of surface mount can lower the cost of components. In addition, this can increase the individual component resistance to environmental stress. [35]

Prototyping usually lasts until all tests are done and all known updates are implemented or can be manually made to the board. Before actual production start, a test sample is usually built by the factory that can verify the quality of the factory or final changes, but nothing significant should be left here. Prototyping early on gives the advantage of developing code in the actual PCB. This can give good insight that test boards cannot. For example, too small wirings can only be tested like this. Each prototyping iteration often needs some similar starting costs as production. Depending mostly on where the prototype is produced, this means the prototyping of PCB costing tens of euros might be from several hundreds of euros to over a thousand euros per prototype. In some cases, prototypes also need tools such as jigs and molds that might not be of use at the production stage if the design varies significantly. [36; 37.]

2.11 Where to produce

It is very common to build consumer electronics overseas, mainly in China. This is usually due to the fact that China produces the electronics cheaper and the availability of materials is better than in most other countries. Thus, the delivery times can even be faster. There are cities that focus mainly on production of electronics and, for example, there can be a district where multiple manufacturers produce solely RC cars and all of the component suppliers reside near them. There are cost-efficient alternatives inside the European Union too. Eastern European countries such as Romania and Bulgaria are known for manufacturers of electronics, and the labor cost there is significantly lower than in the rest of Europe. There are also countries such as Poland, Lithuania and Estonia that have moderate manufacturing costs. They are also branding themselves as quality producers. [38.]

What comes to producing things in Asian markets especially in China, there is always the question of copyrights. China has contracts with the EU about copyrights and patents, but this does not mean that the Intellectual Property Rights (IPR) is safe in the hands of the manufacturers. It is a commonly discussed issue that Chinese companies sell the Intellectual property, IP, of foreign companies and use the most sophisticated methods to copy the designs. Everything from X-ray reverse-engineering, using procedural loopholes and invalidating patents and trademarks with the Anti-Unfair Competition Law are used, and the legal processes may take money and time. [39]

The best practice is to use manufacturers that have big clients, ones the manufacturer do not want to lose. They have most probably already dealt with how to handle IPR . To get the actual prove and validation, sometimes the easiest way is to travel on-site and see the manufacturers, the suppliers and their utilities. This also gives a chance to examine the quality assurance systems, which is common practice. Moreover, manufacturers usually invite new clients to visit their site.

To file for a patent protection in China, the company must file for a patent in China. A foreign company has to use a patent agent to do so. If the patent is filed first in the EU, the patent protection must be filed within 12 months in China. With international patents, the time is 30 months. The patent process takes approximately three years in China. In addition, if the company is commissioning a Chinese company to design something, the commissioned company will own the IPR if not otherwise stated by legal agreement. [40]

2.12 Outcome defined by quality

The quality of the product development reduces the risk of further development costs, and the quality of the production reduces the yield level of finished products, maintenance costs and customer reclaims. The long time maintenance costs usually outweigh the production and development costs if the product is in critical use or if the product is assumed to be premium quality by the end user. When producing cheap electronics that the end user has no high hopes for, a lot can be forgiven and a shorter lifespan is usually well tolerated. End users typically reclaims products or are not satisfied when the expectations do not meet the experience.

Quality assurance is a broad field that does not only involve overseeing software and hardware testing. However, it can include making sure that the needed development tasks are fulfilled and documented in a way that supports quality, continuity and uniformity.

2.13 Import, freight and certification

When the device is manufactured outside the European Union, the import process declares who takes the responsibility as the manufacturer of the device. This applies to the extent that, for example, buying wholesale batteries from China makes the importer their manufacturer in the EU . This also means that the importer is responsible for the safety, use and recycling of the bought goods. When importing a product to the European Union, the importer is responsible solely for making sure whether the product needs European certification, i.e. CE marking. Foreign traders may have import services that allow them to sell goods to the EU countries with their own CE marking, but this practice is not mandatory and might not add value to the seller. [41]

Importing wholesale products usually happens through ocean, railroad or airfreight. Of these, the airfreight is usually the most expensive and the fastest means of transportation. When using airfreight, the expenses are not calculated by weight only but by their volumetric weight as in volumetric kilograms. This is calculated in most carriers, such as DHL, by multiplying the length, width and height of a parcel and dividing it with 5,000 to get the volumetric kilograms. The price of delivery is calculated by whichever gives greater expense, volumetric kilograms or the weight of the parcel. In addition, the carrier usually adds expenses such as extra fuel consumption and traffic expenses. When importing batteries or devices that have radio devices, the radio signals must be turned off during the whole transportation and the batteries need to have testing made according to UN/DOT 38.3. Airfreight with batteries means that the cargo is considered being under Dangerous Goods Regulations (DGR) which means it needs to be delivered to the airport beforehand and stored in DGR housing before flight. This extends the transportation time. [42; 43.]

Freight over railroad is becoming more common between China and Europe while ocean freight is still the most common and cheapest means. For example, it takes approximately 5 weeks to ship something from China to Finland via ocean freight, 2-3 weeks via railroad freight and 2-7 days via airfreight. [44.] Rail and ocean freight need less paper work for DGR shipments but some European ports suspend containers including lithium batteries and examine them before releasing to continue shipments. This causes significant delays and, therefore, DGR shipments are usually routed differently, thus increasing shipment times. [45.]

2.14 Regulations in different countries and the EU

Each country in the EU also has legislation regarding the subjectivity of license to radio devices and batteries. In Finland, Traficom handles the procedures and licensing of radio communication devices. For example, there is no licensing in Finland regarding batteries other than self-regulated CE certification. The customs may keep the devices until certification and testing reports have been seen through by the responsible authorities. In Finland, this takes approximately 2-7 days and, therefore, the shipping time increases. In addition, if a company should import batteries to Finland, the company is legally obligated to take care of the recycling opportunities and availability in the whole country, which is basically impossible for a single company so the responsibility is taken care of by operator associations. There are associations specially made for recycling of electronics, metal derivatives and different batteries. [46; 47; 48.]

Devices to be used and sold in the EU countries need to comply with, for example, General Data Protection Regulation (GDPR)[47], Terms of Service (ToS) [48] and End User License Agreement (EULA) practices [49]. The manufacturer and distributor (see section 4.9 for a definition) is responsible for seeing that the device and service meets these conditions. For radio communication devices to be distributed in the EU, they have to have CE certification. It is solely the responsibility of the manufacturer to make sure the device meets all required CE regulations and to make the EC declaration of conformity. The manufacturer makes sure which Directives and Harmonized standards apply for the device. The documents the manufacturer needs to have are listed below. All of them do not need to be publicly available.

- A general description of the product. This can be a brochure, datasheet or poster that clearly states the company and brand that imports the devices, and the characteristics and features that are of interest.

- A risk assessment to identify the health and safety requirements of the applicable product. The implementation of risk assessment is not specified in the directives and the document does not need to be publicly available unless requested.

- Design and fabrication drawings. This can be a parts list and an exploded view of device parts.

- Detailed technical information on key aspects of the product. This document does not need to be public and can contain detailed information.

- A list of standards and essential requirements that are met. This list is also part of the EC declaration of conformity.

- Reporting of calculations and tests. This document is needed if the product requires tests and calculations to verify the conformity. It can include reports to clarify how certain specifications have been met.

- Certificates and test reports. 3rd party laboratory test reports and certificates if needed from factory and manufacturer.

- User manual. The manual needs to be in all official languages of the country in which it is being distributed. In Finland this means Finnish and Swedish.

The EC declaration of conformity is to be signed by a person authorized by the manufacturer, making personally sure that all CE responsibilities are met. This document does not need to be public but it should be accessible on demand. Sometimes not all devices and their implementation fall within EU directives. The EU also gives recommendations on general and new services that lack the appropriate directives, and it is upon the member country to confirm the recommendations by appropriate authorities.

3 Proposed solution

To bind together the theoretical section, a workflow was designed. This section addresses the issues presented in the theory section such as schedule planning, manufacturing and design resources, testing coverage within budget limit and meeting the certification requirement. This section seeks to implement a realistic plan for starting a product development cycle. The product to be manufactured is an IoT device to be used in light electric vehicles, more specifically a rental electric scooter that is not directly sold to the end-consumer as it stays in the ownership of the manufacturer. The device will need to be equipped with appropriate technology to be used outside the country it was originally imported to, in this case Finland. An estimate on schedule and examples on design implementations and post-manufacturing processes was made for the project. The company already has a similar service running but it wishes to own its technology and develop new features which are not available in the market.

3.1 Requirements to be met

The IoT device will be placed on an electric scooter that is available for rental in the streets of Helsinki. A first patch order size is 400 and the design should stay interchangeable afterwards. This IoT device needs to be small enough to fit a predefined compartment in the electric scooter where it has a maximum space of 100 mm in length, 100 mm in width and 30 mm in height. The compartment is IP67 rated so it will protect the device from dust particles and immersion of water for a short period of time. [50] The IoT device will need to function in mid-summer heat with direct sunlight. To fulfill this requirement, it is desired that the device can be rated to withstand at least 70 degrees Celsius.

The designed IoT device is required to have connectivity to a cloud based backend. Because this backend is already designed, it should communicate with MQTT over TCP/IP. The connection needs to be mobile, reliable and possible to be implemented in another European country if the service is to be expanded quickly. The device will be subject to environmental stress due to vibration, collision and weather changes. The device needs to keep connectivity to backend in case the main power source is drained or malfunctioning, so the IoT device needs to have a backup battery. Furthermore, the IoT device needs to know the exact location of the device and be able to transfer this information to backend. Additionally, a Bluetooth connection is favorable as future development aspects would require this. The device will need to communicate with a motor controller circuit that is connected through a RS232 based UART line. Figure 2 demonstrates the connectivity. The IoT device would enable the GPS/GNSS location, Bluetooth Low Energy connection and 4G connection.

Figure 2. Interconnectivity of the network.

3.2 Project schedule

Because the project is to implement the IoT device once and because further development is not scheduled, it is not considered necessary for the team to hire many new professionals. The company already has developed similar software on the backend side so the company has an embedded systems engineer and a cloud architect to support the development. The device system architecture is scheduled to be ready in no more than 10 weeks with the support from the cloud architect. In the first weeks, an electrical engineer for the PCB designer task is needed to support with the design and start the implementation of the first prototype. The hardware PCB design is scheduled to be finished within three weeks after the system architecture is finalized. This will mean that production can start 14 weeks from the start of the project at the earliest. Because there will probably be no need for the PCB designer after production has started, the design is planned to be consultant work. The firmware development will also need embedded designers to support the development. The design is scheduled to be finalized by the time the hardware is finalized. The development of firmware will continue until production starts. The final release of firmware together with binary that is flashed to the PCB microcontroller is to be made before the beginning of production testing. The team will be continuing with post-development. Most of the firmware development will also be consultant work but an opening for the post-development of firmware should be considered.

An engineering house could provide a team that handles the PCB design, testing design and production design. To manufacture PCB prototypes, a factory somewhere nearby is selected. A Chinese factory will provide the production and the services on supplier sourcing and production planning. There will be a one-time fee and a person is appointed within the project to be the contact person with support from the consultant team production engineer. The factory is chosen so that it can provide these services. The company should also have a good clientship with other European companies to ensure that the IPR can be trusted to them. For production testing, specific testing suites will not be implemented in the first patch. It is decided that flying probe testing will be used on the factory site and that available firmware binary will be flashed at the same time. Firmware flashing can happen also manually on the factory site if needed, and one week is dedicated for the testing of the first patch.

Certification is to be handled by nominating a “person in charge” that will have the right from the company to sign and declare certifications on behalf of the company within the project. A consultant agency is hired to help with the planning. A month worth of work is scheduled to provide the needed documentation with support also from a/the technical team. This person continues to examine the need to update ToS and EULA agreements.

A logistics company is chosen so that the company has offices nearby and in the exporting country, China. The logistics company agents handle freight forwarding and documentation, so a logistics expert is not needed in the project and a person of contact only needs to be appointed. The logistics company will also provide support with customs handling, but the communication between the export factory and the logistics company must be done through the contact person within this project to ensure correct information is passed. Most of the work is scheduled to be done during production. The preliminary schedule planning is shown in figure 3. Some predicted dependencies have been connected in the chart vertically. The document will be updated based on progress and new timeframes. The whole process is estimated to take place within six months but risk factors included a nine-month timeline is possible. This document is to be updated based on the progress.

Figure 3. Gantt chart of designed timeline. Modified from Gantt.com (2020)[6].

3.3 Preliminary technical decisions for IoT device

To start with the design, a communication module needs to be decided that has 4G with a dropback to 2G and a GNSS location service. 2G will secure the connectivity if the devices were to be used in another region where 4G cannot be assumed to work. NB-IoT, Lorawan and 5G modules are left out for the same reason. Many of these modules contain Bluetooth capability, and this would help in future development. The module needs to have EMEA (Europe, the Middle-East and Africa) region bands in data communication. A main MCU unit is needed to instruct the module. To enable the possibility to implement OTA updates in the firmware later, enough memory should be allocated in the MCU or external memory should be implemented. The MCU should be able to handle UART communication with both the communication module and the external motor controller. Interrupt based software architecture should be sufficient, and a low power consumption Cortex-M0 based MCU should be efficient enough. This will also be cost-efficient.

A backup battery should be selected, and it should be small enough to fit the compartment. Heat dissipation should also be handled. In addition, a battery management system, BMS, should be designed in the firmware of the MCU. The battery needs to have certified testing, material safety datasheet and UN38.3 inspected. This should be taken into account on planning resources for both the firmware team and the certification. The battery has to have the ability to be turned off physically during shipment.

These MCU and communication chips are selected surface mount components to gain more freedom of choice. Vibration dampening is to be designed to the edges of the PCB to prevent stress to these components. An external LTE/2G PCB antenna is to be installed at the top of the IoT device compartment and a ceramic GNSS antenna is placed in the PCB board. To fit all components in a PCB that fits the compartment and to safe surface the area of PCB, a 2-sided PCB should be considered.

3.4 Budget estimate

The budget is estimated roughly based on the amount of scheduled work. The work of Electrical and IT sector consultants is estimated at an average of 90 euros per hour [23]. In China, the rates can be considerably lower than in the Nordics [8] so an estimate of 45 euros is used. In the long term, hired staff is cheaper, but in a relatively short timescale, this cannot be depended on. Table 6 illustrates different planned tasks, their number of scheduled work hours and estimated cost. These prices are rough estimates and only give insight. The emphasis is on the consultant work.

	hours	units	á price	made in	total
Architectural design	400		€90.00	Finland	€36,000.00
HW design & implementation	1200		€90.00	Finland	€108,000.00
FW design & implementation	840		€90.00	Finland	€75,600.00
Prototype production x 2		2	€250.00	Finland	€500.00
Production testing design	360		€45.00	China	€16,200.00
Production unit price budget		400	€60.00	China	€24,000.00
All certification and logistics work (inhouse)	160		€90.00	Finland	€14,400.00
Certification consultant fee		1	€5,000.00	Finland	€5,000.00
Freight, import and customs consultant fees and cost		1	€5,000.00	Finland	€5,000.00
					€284,700.00

Table 6. Estimated budget.

Two consultant offices were asked for quotes on the prices of producing an IoT device of similar qualities for the company, but they wish to not have their name connected with a cost estimate. The first consultant house estimated 200,000-250,000 euros on hardware and firmware implementation and the second estimated 200,000 euros. The quotes included work until production start including certification work. Comparing these estimates, they come pretty close to the budget presented here where hardware and whole software design and implementation together with certification work would add to 231,800 euros.

4 Discussion and conclusion

As mentioned earlier, the development process of OEM device requires a considerable amount of interdisciplinary work. The topic is very broad and summarizing it as a simple process is not the purpose of the thesis. The purpose of the thesis is to bring **these parts of the topic together into such a whole** that the overall picture can be perceived on the basis of it. OEMs are easily perceived as large companies that manufacture products by mass production. Based on this study, it is clear that becoming an OEM is not impossible for even a small company even if the company does not want to do everything by hand. High-quality equipment can be manufactured, and the same quality levels and certificates can be met if the work is done purposefully.

The OEM development process takes a substantial amount of resources and needs quite a lot of managing. Estimates are sometimes rough and not based on wide studies but on single quotes. The overall conclusion is that there are considerable variations in the implementation, and practices vary, but the best practices are pretty consistent. Risks on schedules are linked to the complexity of the process, and therefore the estimated 6 to 9 months' timeframe on the proposed solution can be called optimistic. The skills of the professionals working on the project will greatly affect the working hours, schedule and therefore also the budget. The emphasis on quality and agile methods in development has been brought up multiple times. Headlines of industry publications have indicated that the demand for IoT device implementations is substantial. Everyone seems to have an idea they want to implement. The harsh reality is that the cost of implementation is still too high for most companies, but the future looks bright. Easier and faster development tools and half-ready kits are surfacing in the market to help with implementation.

As said in the introduction, the overall process is complicated and contains interdisciplinary engineering aspects. It is not essential to completely understand every detail of every step, but it helps a lot to know where to look for and what the key questions to ask are. The process remains complicated but hopefully someone finds peace with the fact that some people actually really master all of this. It is still difficult to find information on this process as a whole. Quite certainly, however, this work is useful for a person or organization who wants to set out to explore this process. Much of the design and the work itself may end up in the hands of consultants and experts but this can serve as a starting point. Often jumping into the unknown is the hardest part and maybe this makes the unknown look better.

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