# IoT Engineering
# 13: From Prototype to Connected Product


Slides: tmb.gr/iot-13

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## Overview

These slides show *how prototypes become products*.

How to design/build physical, functional prototypes.

How prototyping is a part of the product life cycle.



## Prerequisites

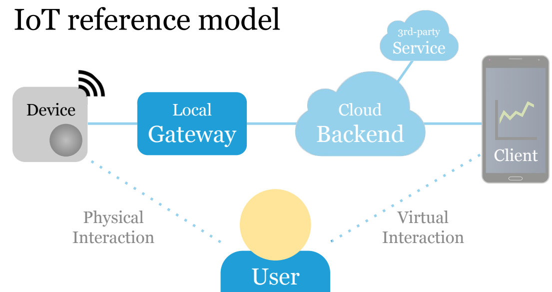
We'll use OpenSCAD software to create a 3D design.

And Cura, a tool to prepare a 3D design for printing.

Hardware is not required for this lesson.



## IoT reference model






## Building connected products

So far we focused on firmware and backend software.

To create a real product, there are additional steps*:

Ideation → Prototyping → Development → Testing → Production → QA → Logistics → Marketing → Sales → Operations → Support → Maintenance → Sunsetting.

*Vendor perspective, there might be iterations.



## Ideation

There are methodologies to find product ideas.

E.g. Know Cards by Alex Deschamps-Sonsino.

Or the IoT Design Kit by Studio Dott in Belgium.

Or Loaded Dice by Albrecht Kurze, TU Chemnitz.

Attending hackdays is another way to get new ideas.

## Prototyping

There are roughly these three variants of prototypes:

Design prototype, how the device will look and feel.

Functional prototype, device/service user experience.

Technical prototype, real hardware, often still too big.

These prototypes can be developed in parallel.



## Prototypes

Left: Functional prototype, most electronics are in the base.

Right: Design prototype.




## Product development

Software / hardware are often developed in parallel.

Technical prototypes are miniaturised, integrated.

Functional prototypes are re-implemented.

Design prototypes are productised.



## Testing and certification

Software and hardware, unit and integration testing.

Field studies, with representative (beta) user groups.

Certification, for each new HW version of a product.

QA at the factory for every instance of a device type.

Monitoring backend services to guarantee SLA.



## Important IoT system qualities

Security, to keep devices, network & backend secure.

Privacy, to keep people in control of their own data.

Interoperability, to become part of an ecosystem.

Openness, standards & open source build trust.

See, e.g. betteriot.org principles for guidance.



## Prototyping at the Fab lab

Small-scale workshop for personal digital fabrication.

Computer-controlled tools to make almost anything:

3D printers, laser cutters, CNC mills, electronics lab.

Coming from MIT, fab labs are a global movement.

What's made in a fab lab can be replicated in others.

## 3D printing

Additive manufacturing, builds objects layer by layer.

Fused deposition modeling (FDM) is commonly used.

Filament materials include PLA and ABS (like Lego).

Stereolithography (SLA) is great for very small parts.

Selective laser sintering (SLS) is rather expensive.

FDM is easy, SLA and SLS take time to learn.



## 3D printing process

Create a 3D model with CAD software, export as STL.

Printer-specific slicer cuts the STL model into layers.

Resulting GCODE file is transferred to the 3D printer.

Printing takes 10-s of minutes up to multiple hours.

There are FDM 3D printers at FHNW Maker Studio.



## CAD software

CAD (computer aided design) tools for 3D modelling:

Commercial tools, e.g. Onshape, Rhino, Solidworks.

Some are free to use for students, e.g. Fusion 360.

Open source tools, e.g. Blender, OpenSCAD.

All of these can export STL files.



## Hands-on, 15': Parametric design

Download OpenSCAD and create a simple 3D design.

OpenSCAD is a domain specific language for CAD.

Objects can be built by subtracting simple shapes.

Design a box that fits a Raspberry Pi Zero.

Export as STL and slice it e.g. in Cura.

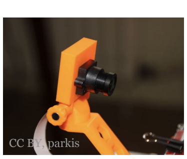
Done? Take a look at this model.

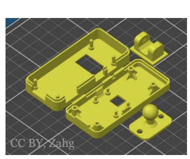


## Design repository

E.g. Thingiverse, for openly licensed 2/3D models.

Here's a selection of Raspberry Pi camera adapters.







## Laser cutting

Create a 2D design with vector based CAD software.

Lasers know vector file formats like AI, DXF or PDF.

Materials include wood & acrylic sheets, up to 6*mm.

Power/speed settings depend on material/thickness.

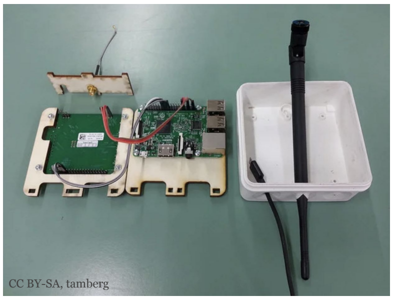
Laser cutting is fast, usually just takes a few minutes.

*Depends on max. power of the laser cutter model.

## Laser-cut adapters

A quick way to fit electronics into an existing enclosure.

This is a simple LoRa gateway.






## CNC milling

Subtractive manufacturing, cuts object out of a block.

3 or more axes, working area from 10-s of cm up to m.

2D or 3D CAD model is prepared with CAM software.

Materials include PCB, foam and wood, metal is hard.

Tool head type and size must be taken into account.

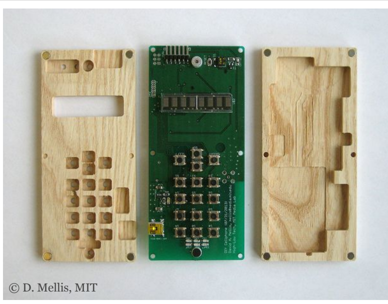
Basic CNC milling can be learned in about a day.



## CNC milled enclosure

Nice materials for prototypes, too expensive in production.

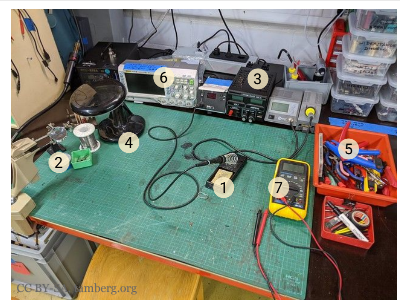
This is a simple DIY cell phone.






## Electronics laboratory

Soldering iron[1], helping hands[2], power supply[3], lamp[4], pliers[5], oscilloscope[6], multimeter[7].






## Designing a custom PCB

A *printed circuit board* (PCB) helps to integrate parts.

E.g. a controller, sensors, a radio & a battery holder.

The traces on a PCB are designed with a layout tool.

Electronic parts come with ready to use footprints.

Layout software includes Fritzing, Eagle or Kicad.



## Producing a custom PCB

Single or double sided PCBs can be etched "by hand".

But it's easier and quite fast to get your PCBs made.

E.g. Aisler, OSHPark, PCBWay make small batches.

Electronic components can then be hand soldered.

## Sourcing parts

The list of all parts is called *bill of materials* (BOM).

Shops for makers include Adafruit, Sparkfun & Seeed.

Electronic parts suppliers are, e.g. Digikey & Mouser.

Or platforms like AliExpress and Taobao in China.

Or, for large batches, contact manufacturers.



## Prototype product

Focused on quick development, OK for beta users.

Off-the-shelf components, easy to use modules.

Off-the-shelf box, or 3D printed enclosure.

Custom PCB, manual assembly/soldering.

Batch size 1 to 100.



## Small batch product

Focused on getting a certified product to real users.

Off-the-shelf, certified modules to save one-off cost.

Off-the-shelf or custom injection molded enclosure.

Custom PCB, automated assembly. Manual QA.

Batch size 100 to a few 1000.



## Mass product

Optimised for cost, ease of use to reduce support.

Custom, certified PCB with integrated modules.

Custom injection molded parts, ~$10k per mold.

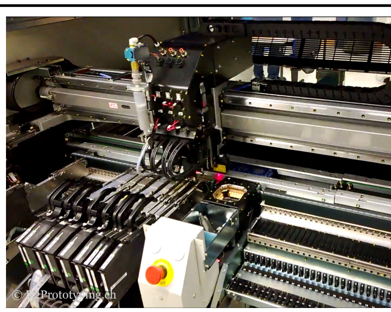
Automated assembly and more automated QA.

Batch size over 10'000.



## Automated assembly

A pick & place machine puts parts on a PCB which are then soldered in an oven.





## Product examples

Opening products is a great way to learn about them:

Avelon Wisely LoRaWAN temp. and humidity sensor.

Gardena smart gateway from Lemonbeat to Internet.

A TTN indoor gateway and the Belkin WeMo switch.

Nest learning thermostat and Amazon Echo device.

## Wisely

MCU, radio module and sensors are integrated on the PCB.

Off-the-shelf enclosure.




## Gardena gateway

Custom PCB with existing Linux SoC[1] and radio module[2].

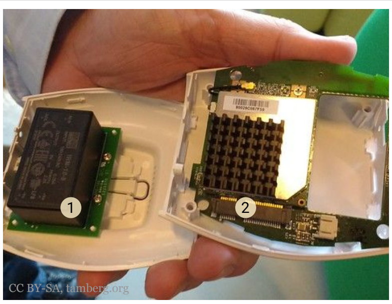
Custom plastic enclosure.




## TTN indoor gateway

Encapsulated power supply[1].

Connector[2] for Wi-Fi module, probably not yet cost optimised.






## Belkin smart plug

Separate PCB for high voltage and Wi-Fi part.

Cost optimised.

See tear-down.




## Nest

Optimised for installation by customer.

Built-in level, spring-loaded wire terminals.

See tear-down.




## Echo

Optimised for audio quality.

Many, complex plastic parts.

See tear-down.

## Hands-on, 15': Second gen products

Compare the Echo Dot (2nd gen) to the original Echo.

What was changed, and what could be the rationale?

If an injection mold is $10k, how much was saved?

Which other parts could bring down the price?

Be prepared to present your findings.



## Lean startup methodology

Described by Eric Ries, in his book The Lean Startup:

*Build, measure, learn*, to discover product/market fit.

*Minimum viable product*, to learn about customers.

*Pivot*, to change course, test a new hypothesis.

This process iterates towards a working business.



## MVP

A minimum viable product, made from off the shelf parts.

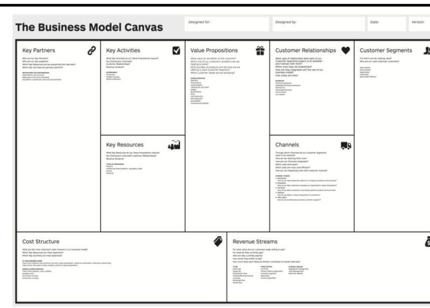
VeloTracker.ch connected bike tracker / light.




## Business model canvas

A tool to prototype business models.

Get it here.






## Summary

We saw the steps involved from prototype to product.

We looked at digital fabrication as a prototyping tool.

We learned about PCBs, layout software, pick & place.

We got some insight into production at various scales.

This was the last lesson before the assessment.



## Feedback or questions?

Write me on https://fhnw-iot.slack.com/

Or email thomas.amberg@fhnw.ch

Thanks for your time.