

Hardware documentation explanation

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Table of contents

A guide to open source hardware projects	8
Technicality	8
Using this template	9
When should you start ?	9
If you have a prototype	9
 I Steps	 10
Step 1 Ideation	11
Ideation	11
Checklist ideation	11
 Step 2 Needs analysis	 12
Needs and ecosystem analysis	12
Checklist needs analysis	12
 Step 3: Concept development	 14
Concept development	14
FBS design methodology	14
Checklist concept development	15
 Step 4: product development and prototyping	 16
Prototyping	16
Checklist 4a: preparations	16
Checklist 4b: iteration of design	17
 Step 5: replicator step	 18
Replication and maturation	18
Checklist replication	18
 II Readme as a first entry door	 19
1 Vision and motivation	20

2	hardware summary overview	21
3	Standard compliance	22
4	Outputs: Products and data	23
5	validation	24
6	education resources	25
7	Cite this project	26
8	scientific publication	27
9	Problem description	28
10	dependencies	29
11	software used for development	30
12	Roadmap	31
13	Project history summary	32
14	Future work	33
15	Community and Contributions	34
16	List of team members / contributors	35
17	Who could contribute	36
18	Communication channel, how to contribute	37
19	License and rights	38
20	Funding information	39
21	Sponsors and funding	40
22	Future funding opportunities	41
23	Administrative information	42
24	ethics statement	43
25	competing interest	44

26 Institutional Review Board Statement	45
27 Documentation structure	46
28 conclusions	47
29 discussions	48
 III Community	 49
30 Community - work culture	50
31 Community -guidelines	51
32 Community –Code of conduct	52
 IV Product development and use analysis	 53
33 product dvt -foreseen cost (money and time)	54
34 product dvt -requirements	55
35 product dvt -constrains	56
36 product dvt -capability	57
37 product dvt -use cases and application	58
38 product dvt -reuse possibilities	59
39 Diverse actors and ecosystem	60
40 user analysis -target groups (who will use the product)	62
41 user analysis - External interfaces (how will they use the product)	63
42 user analysis -skills needed to use	65
43 Functional model	66
43.1 Why should you define functional model?	66
43.2 How to document a functional model?	66
Functional tree	67
Functional graph	68

44 Behavioral model	70
Why should you define behavioral model?	70
How to document a behavioral model?	70
Examples	71
45 behavioral model - behavioral model	73
46 similar projects	74
47 electronics -Software/firmware architecture	75
48 electronics -electrical design architecture	76
 V Structural models	 77
49 Structural model	78
50 Mechanical architecture	80
51 product dvt - Design models	81
51.1 Providing the design	81
51.2 Modelling a design in an editable file format	81
Template of file format	82
3. Characteristics of the materials	82
Template of material Characteristics	83
52 Software and Firmware architecture	84
52.1 Details	84
53 Electrical architecture	85
53.1 Details and editable format: PCB design	86
 VI Project history	 88
54 Project history -changelog.md	89
55 Project history - release notes	90
56 Project history -design choices	91

VII user guides	92
57 Guide for Users	93
57.1 What is the user guide?	93
57.2 How to create a user guide ?	93
58 User Guides : Safety information	95
59 User Guides - Overview of the hardware	96
60 Operation instructions	97
61 User Guides: Troubleshooting	98
61.1 Testing instructions	98
61.2 Troubleshooting	98
62 User Guides: Calibration	99
63 User Guides : Repair	100
63.1 Identifying the defective components	100
63.2 Repairing the defective components	100
64 User Guides: Replacing equipment components	101
65 Maintenance	102
65.1 Maintenance instructions	102
Template of maintenance	103
66 Disposal instructions	104
Classing elements	104
Types of disposal:	104
disassembly	105
environmental assessment	105
Template of disposal	105
67 User guides: Environmental management	106
VIII Product build	107
68 Hardware production	108
68.1 Production instructions should include:	108
68.2 Helping workflow and software	109

69 Product Build: Bill of material	110
69.1 Modularisation	110
70 Product build -material characteristics	112
71 Product Build: Electrical design	113
72 Product build -firmware/Software	114
73 Product Build: Manufacturing skills	115
74 Product build: Manufacturing tool	116
74.1 Type of machines	116
75 Product build: Manufacturing sequence	118
75.1 What does include the documentation of manufacturing sequences and instructions?	118
75.2 Example of parameters	119
76 Product Build: Assembly sequence	122
76.1 Part list	122
76.2 Sequence	122
76.3 Notes	123
77 Product Build: Assembly skills and tools	124
77.1 Example of skills and machines:	124
78 Sources	125
78.1 Open next work	125

A guide to open source hardware projects

This book presents explanations for elements of the hardware project documentation template. The documentation should grow with the project size, and should not limit itself to the technical aspects of the hardware (how to rebuild it), but should present the project in its entirety, such that new users and new collaborators can find the information they need to participate in the project.

The book chapters follows the different elements of the template (readme, community, project history, conceptualisation and specification, hardware design, and user guides). In addition, the firsts chapters present the steps proposed for the development of the project (ideation, needs analysis, concept development, prototype, replication and use), linking to the sections relevant for that development step.

Because we expect most project to see this template when already having a prototype, we added a special chapter on starting at this stage (@sec-whenstartingdocumentations).

Note_1: hardware development per se starts only in step four, the preparatisec-whenstartingdocumentationon phase is important if one does not want to end up reinventing the wheel or producing useless hardware. Note_2: Step 1-3 have an iterative nature: Especially, the analysis of “Similar projects” coming in step 3, and the prototyping (step 4) are often giving new ideas and refining use cases.

Technicality

This is a quarto book, each element has its own quarto/markdown file. See the Git repository (<https://github.com/open-make/RHardware-minimaltemplate>) to modify this book.

Using this template

When should you start ?

This template allows you to start documenting your project at the ideation phase. While it might seem too early, it is useful when you want to present your ideas to collect feedback or even find collaborators. This allows to make clearer what are the important aspects of your idea, and can start interesting discussions.

If you have a prototype

We expect most readers will come to this documentation template when they actually already have a prototype, and are mostly interested in the documentation of the technical parts of the project (mostly what will be in the 04__hardware folder). If you are in this situation, our advice is to go through each steps rapidly, making either short description of what you had in mind when doing the project or noting what you may have done only sub-consciously. Look at the checklist below and the provided template “Full_Project_prototype”, and go rapidly through it to get to the prototyping phase early. When you are happy with the results, go back to the things you noted earlier and see what is still relevant. For example, the needs and actors analysis may help you find or define a target group for your hardware, and help you find your users, and the conceptualisation documentation may help discussion with contributors.

Part I

Steps

Step 1 Ideation

Ideation

At this step, you want to share your idea, usually with a small number of people, and want to “test the water”.

Checklist ideation

This should all be included in the readme file:

- ☐ General information
 - ☐ name of the project
 - ☐ development stage: idea generation
 - ☐ *type of hardware, subject area*
 - ☐ **License(s)**
 - ☐ FOR WHO IS MADE THIS DOCUMENT
 - ☐ short problem description
- ☐ vision and motivations Chapter [1](#)
- ☐ Contributions
 - ☐ List of team members / contributors Chapter [16](#)
 - ☐ skills required, who could contribute (at this point) Chapter [17](#)
 - ☐ contact point information / communication channel and tools used for communication (this can also be one email address) Chapter [18](#)
- ☐ Funding information
 - ☐ List of Sponsors and funding Chapter [21](#)
 - ☐ List of putative funding opportunities Chapter [22](#)

Step 2 Needs analysis

Needs and ecosystem analysis

Using a open source hardware canva to analyse the project may be useful at this point (defining users, contributors, communication channels, resources required).

A lot of the user analysis and the problem description part aims at the definition of the constrains and requirements for the hardware which is included in the product development part of the documentation.

It may also be time to work on community engagement.

Checklist needs analysis

- ☐ Complete the readme file
 - ☐ *ethics statement (human/animal use or Informed Consent Statement)*
 - ☐ *competing interest*
 - ☐ future work, roadmap
 - ☐ development stage: needs analysis
 - ☐ *Project history summary*
 - ☐ longer problem description
 - ☐ Documentation structure
- ☐ Contributions
 - ☐ Contribution guidelines
 - ☐ work culture that you want to promote
 - ☐ Code of conduct
- ☐ User analysis (this can be a personas analysis)
 - ☐ Ecosystem analysis (**stakeholder**)
 - ☐ target groups (who will use the product)
 - ☐ External interfaces (how will they use the product)
 - ☐ skills needed to use
- ☐ Product development

- ☐ requirements
- ☐ constrains
- ☐ capability
- ☐ History
 - ☐ *changes log*

Step 3: Concept development

Concept development

After having an idea and defining the problems, now is time to look at putative solution. This step aims at researching the technology that will be best adapted to fulfill the requirement and constrains.

If possible, one should try to define the **Modular architecture** of the hardware, which describes **architecture of functions and instructions of the product**.

An important part of this step is the research of similar project. You may end up joining an existing community and extending (adding a new module) or adapting an (or combining several) existing open hardware solutions.

Usually, this step ends with a redefinition of the needs and vision, and the three first steps often are iteratively determined until a concept is chosen for the first prototype.

Durability and repairability constrains should be included at this point of the design. While this will be mostly documented in step 5 with repair and disassembly instructions, these concepts should be incorporated early in the design.

FBS design methodology

The concept phase is the main design phase of the hardware. While in practice, it is often made in parallel to the prototyping, larger project should invest some time at this step, and the use of the Function-Behaviour-Structure (FBS) design approach will facilitate future co-design:

- **Function (F)** stands for “**what the object is for**”.
- **Behaviour (B)** stands for “**what the object does**”.
- **Structure (S)** stands for “**what the object consists of**”.

Checklist concept development

- ☐ Complete the readme file
 - ☐ development stage: concept development
 - ☐ dependencies
 - ☐ *conclusions*
 - ☐ software used for development
 - ☐ hardware summary overview
- ☐ History
 - ☐ release note
 - ☐ design_choices
 - ☐ update change log
- ☐ Product development
 - ☐ update hardwareoverview
 - ☐ application, use cases
 - ☐ *reuse potential*
 - ☐ architectural structure
 - ☐ *foreseen cost + time cost*
 - ☐ functional model
 - ☐ Behavioral model: *Modelling tool list* Chapter [44](#)
 - ☐ Similar projects

Step 4: product development and prototyping

Prototyping

Here the work on the design starts! Continuous documentation of choice made, successes and failures are welcome, so this step has an iterative components: with every development can come specific documentation.

In addition, the documentation may need to be performed for different parts (or modules) of the hardware.

Importantly, the Product design, manufacturing and assembling instruction may be organised using different strategies. Some projects may write simple text files like the rest of the documentation; other projects may use Gitbuilding to write the assembly instruction, and deriving the bill of material from it; other projects may derive assembly instructions from their CAD files.

This step is also divided in two: a preparatory phase defining the main components and an iterative phase which can change with the different version of the hardware.

Checklist 4a: preparations

- ☐ Complete the readme file
 - ☐ development stage: prototyping
 - ☐ Standard compliance
 - ☐ Product outputs (if relevant: data outputs)
 - ☐ Citing information
- ☐ Product development
 - ☐ Structural architecture
 - ☐ Mechanical architecture
 - ☐ Software/firmware architecture
 - ☐ Electrical design architecture

Checklist 4b: iteration of design

- ☐ Complete the readme file
 - ☐ Update Documentation structure
- ☐ Product design
 - ☐ Bill of material
 - ☐ material characteristics
 - ☐ electrical design
 - ☐ Software: Documentation of different parts
- ☐ Manufacturing instructions
 - ☐ Manufacturing skills and tools
 - ☐ Manufacturing sequences and instruction
- ☐ Assembly instructions
 - ☐ assembly skills and tools
 - ☐ Safety information
 - ☐ Assembly sequence and instruction
- ☐ User guide
 - ☐ Safety information
 - ☐ overview of the hardware
 - ☐ Operation instructions
 - ☐ Testing instructions and troubleshooting
 - ☐ basic maintenance + schedule
 - ☐ basic disposal
- ☐ History
 - ☐ update changelog/release note
 - ☐ update design choice history

Step 5: replicator step

Replication and maturation

Here the prototype is mature enough that it should be replicated in different places. While most of the work was already present at step 4, here we go into more quality and details.

Checklist replication

- ☐ Complete the readme file
 - ☐ development stage: replication ready
 - ☐ scientific publication
 - ☐ education resources
 - ☐ Institutional Review Board Statement
 - ☐ discussions
 - ☐ validation
 - ☐ cost
- ☐ Assembly instructions
 - ☐ disassembly instructions
- ☐ Product design
 - ☐ component lifespan
- ☐ User guide
 - ☐ Environmental management
 - ☐ Identifying the defective components
 - ☐ Repairing the defective components
 - ☐ Replacing equipment components

Part II

Readme as a first entry door

1 Vision and motivation

The vision provides details about the project ultimate goal, its specificity and main objectives: what, for whom and why do we have this project.

It serves to give meaning to the whole endeavor and is a representation of what we want to achieve. It may also present the problem the project aims at solving.

It addresses the question: Why are you starting this project?

Examples:

The OpenFlexure project makes high precision mechanical positioning available to anyone with a 3D printer - for use in microscopes, micromanipulators, and more.

This projects aims at providing fablabs and makerspaces with pedal powered toolkit, in order to open discussions around the principles of [low technologies](#): especially questioning needs (do we need the object), and designing while recognizing the ecological impact (choice of material, improving durability and repairability).

One single pedal “motor” will be connected with several tools usually requiring a rotating motor (sewing machine, saw, ...). The main goal is to question the use of electrical power and show the simplicity of the tool in fablabs. The multifunctionality is important for the concept of sufficiency (less resources for a similar output). An additional goal may be to enhance collaborative work (one need two people to use the tools).

We think this may also help solves the problem of “building fancy but useless objects” we sometimes see in fablabs, when objects are build to show one’s skill and the possibilities of the machines, but they do not answer any needs.

The project BCN3D Moveo is motivated by the high cost of the materials that undergraduate students must use for learning how to engineer mechatronics systems.

Sources

OpenNext work project resutls: [Section 78.1](#)

2 hardware summary overview

This part is meant to give an overview of the hardware, more detailed description should be given in the 03__product__dvt/hardware__overview.md file.

A schema, a picture or a video may be added here.

At first, one can state what will be delivered in this project?

Example:

The project [BCN3D Moveo](#) is an open source robotic arm that everyone should be able to replicate - with or without modification - at home without the need for highly technical knowledge and expensive materials. The robotic arm will support several of the existing training itineraries: mechanical design, automation, industrial programming, etc.

Sources

OpenNext work project results: Section [78.1](#)

3 Standard compliance

Please indicate if the hardware is compliant with standards.

4 Outputs: Products and data

This section define the product or data produced by the hardware.

example:

5 validation

6 education resources

7 Cite this project

8 scientific publication

9 Problem description

10 dependencies

Here it is welcome to acknowledge the existing sources that have been used in this project with locations, and name their initiators. At best, present dependencies following what these projects provide as citation information. But at least:

- Initiators of the original project
- URL of the original project

You may also cite projects that project is citing as dependencies or source, with the URL of other related projects

Sources

OpenNext work project results: Section [78.1](#)

11 software used for development

12 Roadmap

13 Project history summary

Indicate main information about the history of the project, as well as the last updates in the project and in the documentation (especially if the documentation is not up to date).

14 Future work

15 Community and Contributions

16 List of team members / contributors

Describe here who are the maintainers and the main contributors of the project, indicate their name, role in the project and link to further information.

- Avoid giving personal information (like emails) in the documentation itself. One non-personal email (or not recognisable email) can be given as a communication tool.*

17 Who could contribute

Mention the specific knowledge a contributor shall own to contribute to the project, as a maker or as a different role, indicate what kind of skills you are looking for.

Describe here how people can contribute to your project. What is the preferred workflow and mention what is the agreement.

Example of a contribution process:

Post an issue on the Git Forge and briefly outline the changes you plan to make or would like to be made.

18 Communication channel, how to contribute

In first step, this can be restricted to give an email where newcomers can ask for further information. If you are using a Git Forge, the issue system of the forge may be linked here.

In developed project, a forum page or the use of a community communication tool like mattermost or matrix (to give two open source examples) is often better, as the community can work decentralised.

19 License and rights

Under what license is this open-source hardware documentation provided ? Specify when different part of the documentation have different license

- [Comparison of free and open-source software licences](#)
 - [license of open hardware projects](#)
-

Sources

OpenNext work project results: [Section 78.1](#)

20 Funding information

21 Sponsors and funding

Who is sponsoring your project?

- URL:
 - Name:
 - E-mail address:
 - grant number:
-

Sources

OpenNext work project results: Section [78.1](#)

22 Future funding opportunities

It is often a good idea to list putative funding opportunities when the project has no long term financing. An indication of the strategy followed by your community is also a sign of how open the project is and will be in the future.

23 Administrative information

24 ethics statement

25 competing interest

26 Institutional Review Board Statement

27 Documentation structure

How is your documentation organized?

These guidelines will provide you with a standard structure that is mainly following the product life cycle and the technological decomposition. It is implemented in the documentation template available in this project.

Sources

OpenNext work project results: Section [78.1](#)

28 conclusions

29 discussions

Part III

Community

30 Community - work culture

31 Community -guidelines

32 Community –Code of conduct

Part IV

Product development and use analysis

33 product dvt -foreseen cost (money and time)

34 product dvt -requirements

A requirement is a formal statement that specifies when condition C is true, property P of object O is actual and its value shall belong to domain D .

It is usually defined at the end of the ecosystem and user analysis.

- The minimum set of independent requirements can completely characterize the needs of the product in the functional domain.
- Functional requirements describe qualitatively the system functions or tasks to be performed in operation.
- Requirement can state as follows: The [stakeholder] need [Property] [object] [Action verb] at [Condition]

Example of the functional requirement that ADD-ONS of XYZ cargo provides for the food producers, as a stakeholder, to preserve the quality of food.

In this example, we assumed a refrigerator on the ADD-ONS could help the food producers to cool down and preserve the temperature of food.

So, we defined some functional requirements (FR) based on this assumption that consist:

- FR1: To maintain the quality of food, the food producer needs to main the material at cold temperature (between 3 °C and 10 °C) for short-term preservation (3h) or long-term preservation (24h).
- FR2: ADD-ONS shall fix the internal ADD-ONS >temperature for 7 °C.
- FR3: To create a cold ambient in the cooling down system, the ADD-ONS shall compress the low temperature and pressured gas to start the cooling cycle.
- FR4: the cooling down system shall control the pressure of exit hot gas
- FR5: the hot and pressured exit gas needs to meet the cooler external ambient temperature to become a liquid.

Sources

OpenNext work project resutls: Section [78.1](#)

35 product dvt -constrains

A constraint is a choice that makes certain designs “not allowed” or inappropriate for their intended use.

- The constraint is a restriction, limit, or regulation imposed on a product.
- There are two kinds of constraints: input constraints and system constraints.
 - Input constraints are imposed as part of the design specifications.
 - System constraints are constraints imposed by the system in which the design solution must function.

Example XYZ Cargo ADD-ONS, constraints for maker of ADD-ONS

- User should be able to dismantle ADD-ONS with a maximum one wrench and one screwdriver
- Users should be able to customize the modules of ADD-ONS to fit their use.
- The ADD-ONS should enable the users to do the assembly of components in a short time (10 minutes) and the maker shall select the resistance material for using ADD-ONS in different weather conditions.
- ADD-ONS should be dismantled for recycling purposes.

Sources

OpenNext work project results: Section [78.1](#)

36 product dvt -capability

A service or capability is an effect intended by a actor/user resulting from the interaction of the product with its environment (i.e. what the product is for).

NB: this will relate to the user analysis section of the documentation that defines the actors and interactions.

- **Services can be stated as follows: The [Product] shall enable [the actor] to [Action verb] (for example The product shall enable end-user to clean its teeth)**
- Services provide users with an exchange value that can be included in an economic system.
- Services are intended effects that can be observed from outside the product (“black box” external view).
- Services are defined in a solution neutral-way.

Example of services for ADD-ONS of XYZ Cargo

- The ADD-ONS shall enable the food producer to store food
 - 1.1 solid (10 kilos)
 - 1.2 liquid (5 litres)
- The ADD-ONS shall enable the food producer to heat food
 - 2.1solid (150 deg Celcius)
 - 2.2 liquid (80 deg Celcius)

Sources

OpenNext work project results: Section [78.1](#)

37 product dvt -use cases and application

38 product dvt -reuse possibilities

39 Diverse actors and ecosystem

this is sometimes referred to a "stakeholder analysis", but we avoided that term in this template.

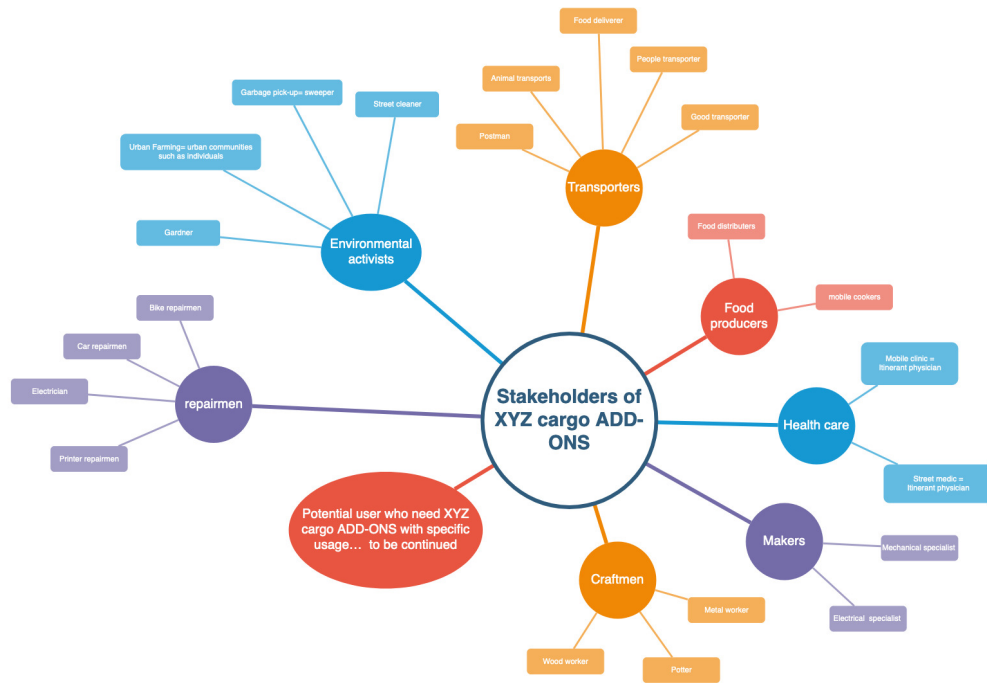
The ecosystem generally refers to all the actors (human and non-human) who (may) have an interest in a product. Among them, there are both internal players, such as users and participants of the project, and external players that are represented by the potential user of products or external entities.

- It is not necessarily a person (for example: airports as an actor when designing a two-deck aircraft).
- They can indirectly affect, be affected by the product (for example: neighborhood or biodiversity when designing an airport).

The ecosystem is often best represented via a graphics or a mindmap. This analysis may be necessary to make design choice that will fit the ecosystem inside which the hardware is supposed to work.

NB: The user target groups is one of these actors and should be determined with more accuracy, it is defined more extensively elsewhere.

Example



XYZ Cargo-ADD ONS

Sources

OpenNext work project results: Section [78.1](#)

40 user analysis -target groups (who will use the product)

41 user analysis - External interfaces (how will they use the product)

External interfaces are interactions between the product and the actors (including users).

- An interface has a direction (in, out, or in-out)
- An interface is made of a flow (matter, energy, or signal)

Example: XYZ Cargo ADD-ONS

Identify the interactions between food producer and the product, **specify needs and uses**: - out: mechanical containment - out: warmer and cooler - out: thermal energy

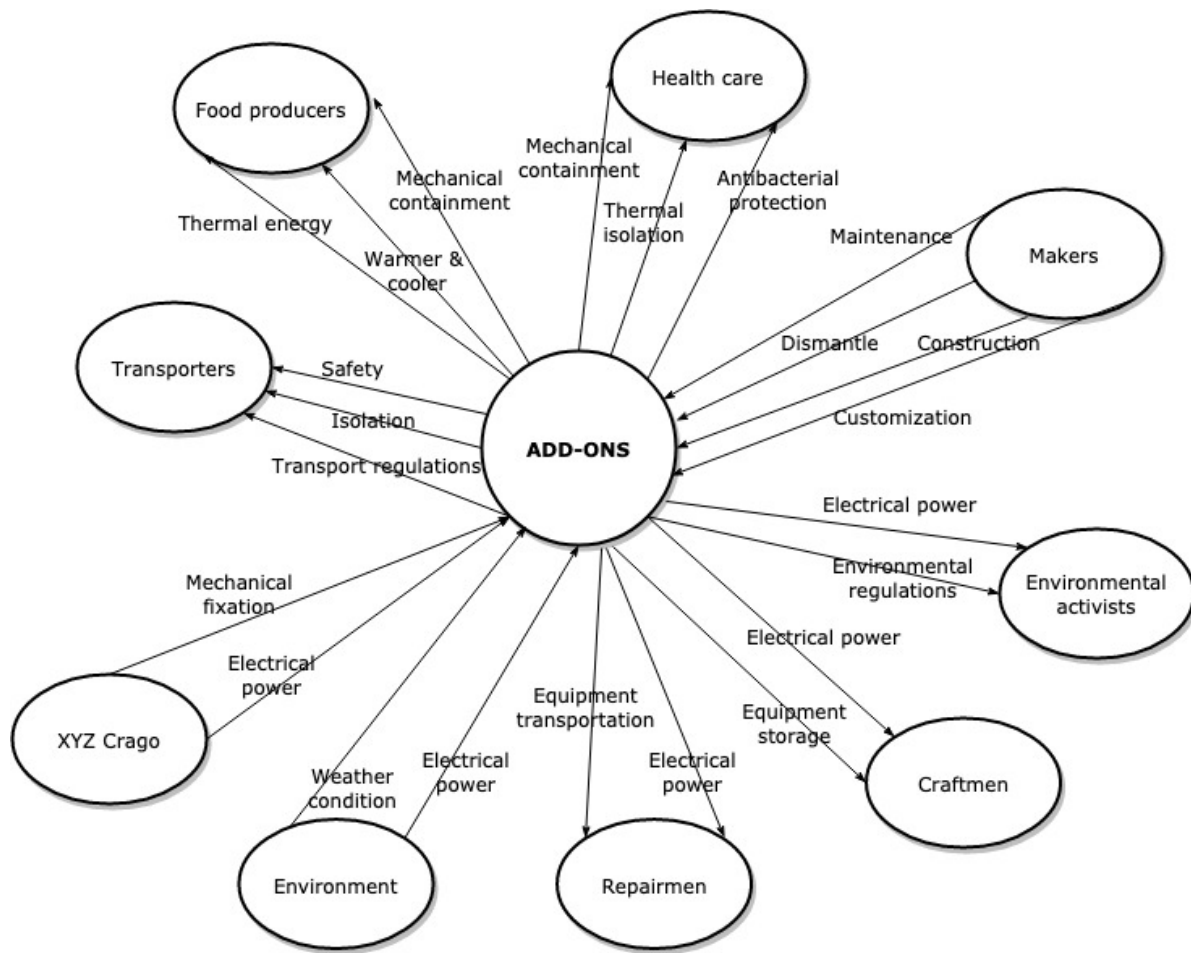


Figure 41.1: Image of External interfaces of XYZ cargo-ADD ONS

Sources

OpenNext work project results: Section [78.1](#)

42 user analysis -skills needed to use

What is the specific knowledge a maker shall own to reuse - without modification - your product ??

For example:

The project echopen need basic knowledge about the medical ultrasound technology such as ultrasound imaging, a matter of acoustical impedance, etc.

Sources

OpenNext work project results: Section [78.1](#)

43 Functional model

A Functional model explains what the product is made for. It is:

- A description of the functions performed by a product.
- An opportunity to break down a product into smaller pieces (modules) that can be more easily understood.
- At the highest level of a functional breakdown (black box view), service functions are the effects (intended by its ecosystem actors) of the interaction of the product with its environment. (See actors analysis, Chapter 39).
- At the intermediate and lowest levels of a functional breakdown (white box view), technical functions are input-output relationships transforming matter, energy or information flows. They are expressing in a non-solution neutral way and observable from inside the product. A set of technical functions is necessary for the realization of a service function (in contrast to solution neutral expression of the capabilities, Chapter 36).

43.1 Why should you define functional model?

- A functional model helps to break down a complicated problem into simple sub-problems.
- A functional model helps to anticipate failures occurring when an intended effect of the product is no longer produced on its environment.
- A function is the main input to derive the functional requirements required to define the conditions of use of the product as well as to provide objective evidences through the validation and verification activities.

43.2 How to document a functional model?

- The documentation of technical functions, which requires adopting an internal (white box) viewpoint on the product, consists in breaking down the service function into sub-functions. The decomposition process is no more solution neutral as it requires to make a decision at every indenture level. The functional decomposition requires two modelling approaches: function tree and functional graph.

See also Chapter 49 for the technical description of creating trees and graphs.

Functional tree

The functional tree is a top-down decomposition of function into sub-functions that helps to simplify the problem to solve.

The decomposition of technical functions creates a functional tree and, the technical functions are defined based on the functional requirements.

- A top-down and bottom-up reading of the functional tree provides insight on the “how” and “why”, respectively.
- The decomposition process should be stopped when the technical function is sufficiently detailed to reuse, make, or buy a design solution.

Example

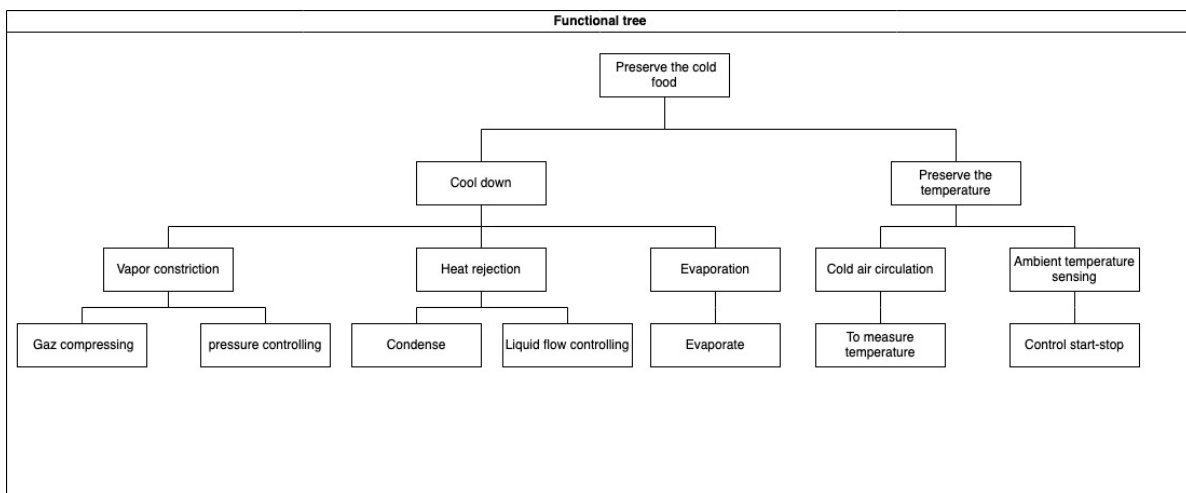


Figure 43.1: Image of functional tree of XYZ cargo-ADD ONS

1. What minimum documentation should the functional tree provide?

- A model specifying the kinds of technical functions and their sub-functions in the format of a tree.

2. How to implement the functional tree?

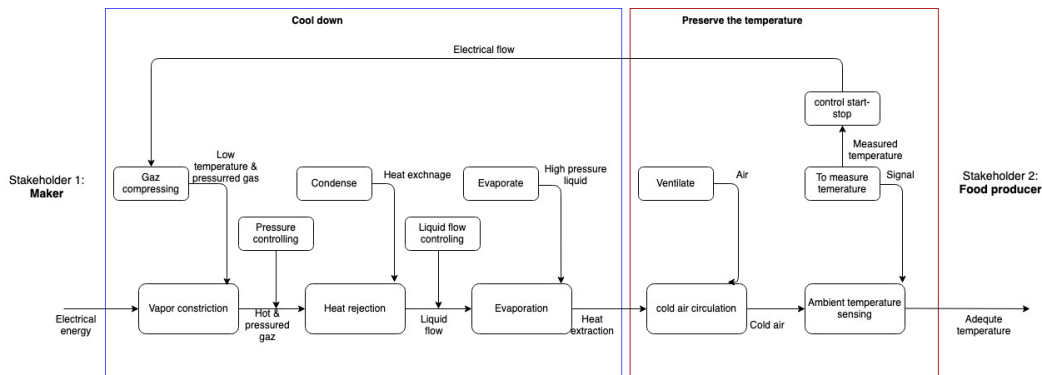
- Use functional modeling language for representation, such as
 - UML (Use Case diagram)
 - SysML (Block Definition, Activity, or Internal Block diagram)
 - SADT/IDEF0
 - Functional flow block diagram

- Use open-source software for modeling the tree representation, such as:
 - draw.io (diagram.net)
 - excalidraw
 - Papyrus
 - Modelio
 - Capella

Functional graph

The functional graph is a multi-level logical articulation of technical functions. - Relationships between functions are in/out-going flows of matter, energy, or information. - Logical AND/OR gates can be used to define concurrent or sequential functions. - Articulation of technical function can describe as input-output relationships transforming flows by using the functional modeling language in the format of the graph

Example



The image shows the functional graph of the relationship between technical functions for maintaining food quality by ADD-ONS of XYZ cargo.

See Chapter 49 for information about creating tree and graph

1. What minimum documentation should the functional graph provide?
 - A model specifying a multi-level logic of relationships between technical functions (refer to functional graph of XYZ Cargo-ADD ONS)
2. How to implement the functional tree?
 - Use functional modeling language for representation, such as
 - draw.io (diagram.net)
 - excalidraw

- UML (Use Case diagram)
 - SysML (Block Definition, Activity, or Internal Block diagram)
 - SADT/IDEF0
 - Functional flow block diagram
- Use open-source software for modeling the tree representation, such as
 - Papyrus
 - Modelio
 - Capella

The link below shows an example of functional block diagrams of an open-source project

[Functional diagram of Renesas ventilator](#)

Sources

OpenNext work project results: Section [78.1](#)

44 Behavioral model

The model will enable the makers to understand the analysis of the physical behavior of a product, this analysis supports the decision made at the later stages of design. This analysis is most often done using simulation software, or is made unconsciously in the designer head. Having some explicit model (even when no software is used) can be very useful to share ideas between designers.

The behavior model:

- describe the behavior of a product when it receives a stimulus.
- could be the mathematical description of the physical product, this description may be made via a modelling software (Simulation model) that should be included in the documentation.
- is the physical interactions between the components of a design, as well as between the design and its environment. An artifact exhibits certain behaviors not only by the change or maintaining of its physical state, but also by several interactions that take place inside the artifact, as well as with its environment.

Why should you define behavioral model?

- The behavioral model identifies the properties for understanding the calculation, simulation, and environment of the product.
- The behavioral model could provide the simulation of any given physical phenomenon using numerical techniques.
- Behavior model describes how the artifact implements its function and is managed by engineering principles and physical rules that are included in a behavioral model.

How to document a behavioral model?

Documentation should indicate the type of model, variables used to define the model, software used for the simulation, and results of the simulations.

Examples

- type of model:
 - mechanical simulation (finite element analysis (FEA) and computational fluid dynamics (CFD) are two types of mechanical simulation)
 - physical simulation
 - Thermo-mechanical simulation
 - Electronical simulations
- variables used in the model:
 - Specification of the geometrical model (refer to editable file format in the structural model)
 - Material characteristics (refer to structural model)
 - Initial conditions such as initial stresses, temperatures, velocities.
 - Boundary conditions can be imposed on individual solution variables such as displacements or rotations.
 - Kinematic constraints that are several of the fundamental solution variables in the model (Linear constraint equations) or multi-point constraints (General multi-point constraints) can be defined.
 - Interactions that are contact and other interactions between parts can be defined.
- (open-source) Software :
 - Open Modelica
 - ADINA

Examples

Example 1: [FinEtools: Finite Element tools](#)

Example 2: Image below shows the simulation of the torsion of the fixed part from below and its evaluation of the reality.

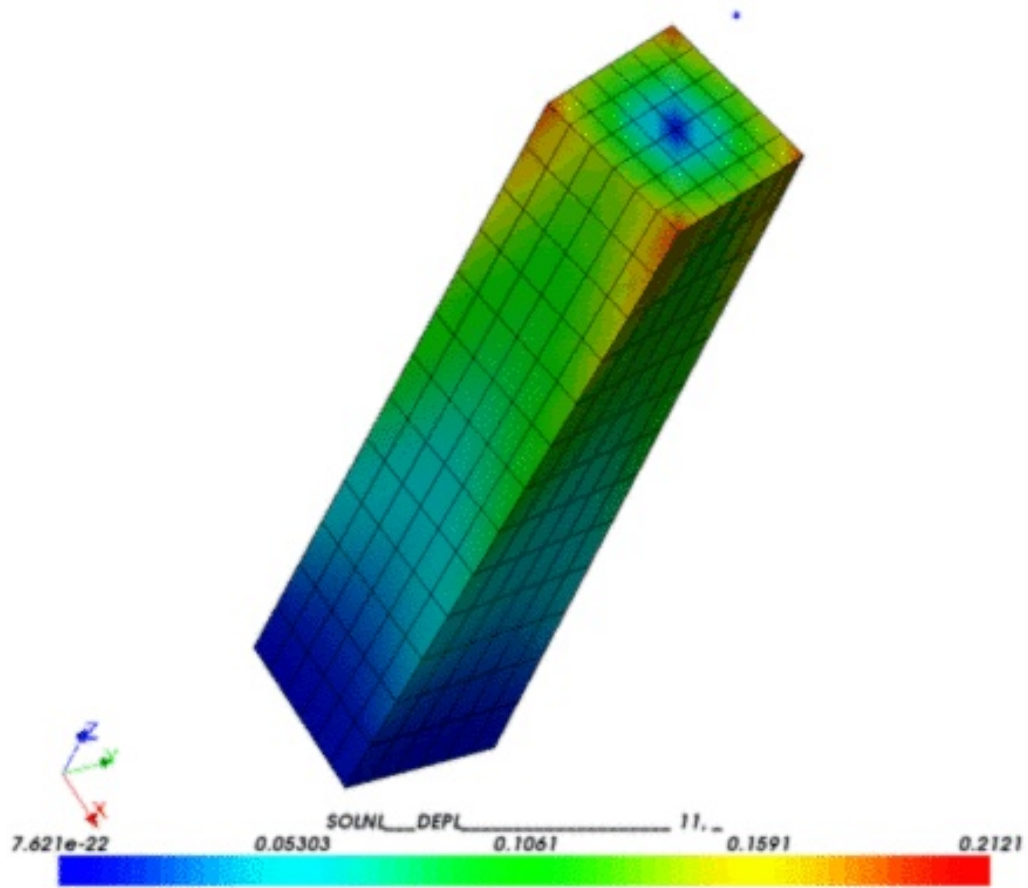


Figure 44.1: Image of Finite element analysis

Sources

OpenNext work project results: Section [78.1](#)

45 behavioral model - behavioral model

46 similar projects

47 electronics -Software/firmware architecture

48 electronics -electrical design architecture

Part V

Structural models

49 Structural model

This section will give an overview of the structural model, while details are given in the specific mechanical (also called architectural, Chapter 50), electrical (Chapter 53) and software (Chapter 52) architectures sections. Note that sometimes, these different models are presented together in a single graphics.

The Structural model explains the physical structure of the product and its components, it is:

- A description of the components (the combination of parts) of a product and their relationships.
- An opportunity to specify the geometric elements, dimensions, topology, and other physical properties of the product.
- The potential solutions (concepts), which are the result of the conceptual design phase.
- The set of mechanics theories that obey physical laws required to study and predict the behavior of structures.

Why should you define structural model?

- A structural model helps to describe the geometric elements (design feature, dimensions, constraints, etc.), topology (assembly constraint between components, tolerances, components mating conditions, etc.), and characteristics of the product.
- A structural model helps to decide the physical form of the product and its components to ensure that the structure is fit for its intended purpose.
- Structural model provides users with a physical model of the product, components, and characteristics of the material at the design phase that enable the stakeholder to understand the geometry, material reaction to external factors, etc.
- The structural model ensures that the structures are safe and fulfill the functions for which they were built.

How should you define structural model?

The first level of definition is often to show how things are related together in a tree or graph, using “modeling language” such as “SysML (Block Definition, Activity, or Internal Block diagram)” or “UML”.

Several software may help create these graphs:

- Papyrus

- Modelio
 - Capella
 - diagrams.net (previously draw.io)
 - <https://excalidraw.com>
-

Sources

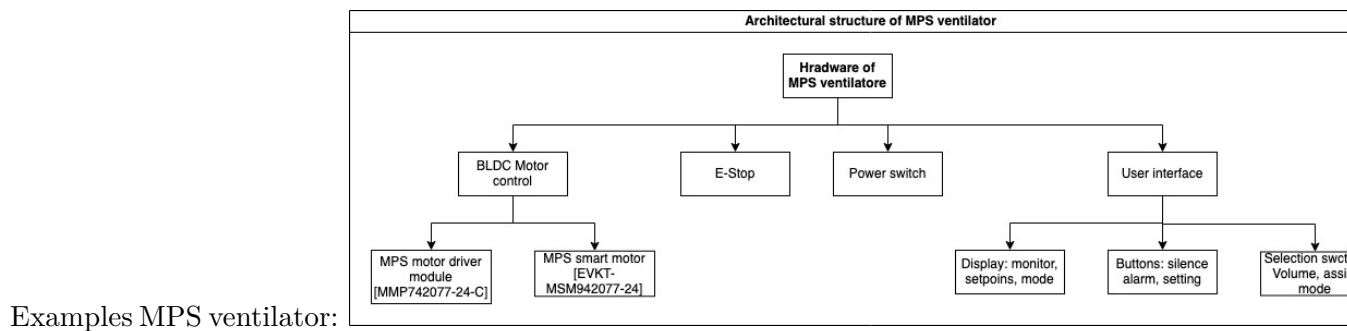
OpenNext work project results: Section [78.1](#)

50 Mechanical architecture

The architectural structure is a physical or logical layout of the components of a system design and their internal and external connections.

- A model specifying the kind of components and their sub-components in the format of a tree or a graph

See for information about how to document this. Provide both an image and the editable files, as well as instruction how to use them.



Sources

OpenNext work project results: Section [78.1](#)

51 product dvt - Design models

51.1 Providing the design

Model design should be provided in a format that can be used to manufacture each piece (usually STL file for 3D and SVG file for 2D design).

51.2 Modelling a design in an editable file format

An editable file format is a standard way that information is encoded for storage and allows the makers to study, modify the geometry of a model and reuse it.

To reuse a design model, it should provide information consist of:

1. Preferable 3D/2D file format
 - Editable file formats that could be:
 - Native formats such as .FCStd format of FreeCAD
 - Neutral formats such as STEP files
2. Preferable open-source software
 - OpensCAD
 - Inkscape
 - FreeCAD

Click to see the examples!

Example of editable file formats:

1. *Farmbot, Native CAD files*
2. *MIT Emergency Ventilator, Neutral CAD files*
3. *Types of CAD format of [transmagic](#)*

Template of file format

Documentation a design in an editable file format 1. 3D/2D file format * Native formats * Neutral formats 2. Name of software * FreeCAD * ...

3. Characteristics of the materials

Click to see the guideline!

- **Definition:** *The characteristics of the materials are those that identify the reactions of materials reactions to heat, electricity, light, force, etc.*
 - *Selection of materials based on factors including properties for [behavioral](#) analysis, [environmental impact](#), [manufacturing](#) processes in design reuse.*

The material characteristics of mechanical parts consist of:

1- Identifying the kind of characteristics and their properties:

- Mechanical characteristics like hardness, elasticity, plasticity, toughness, etc.
- Manufacturing properties like castability, machinability rating, etc.
- Thermal characteristics like melting point, thermal conductivity, etc.
- Electrical characteristics like electrical resistivity and conductibility, etc.
- Chemical properties like corrosion resistance, surface tension, etc.

Click to see the examples!

Example of material characteristics:

Figure below shows some physical properties of superalloy base elements.

Crystal Structure		Melting Point		Density		Expansion Coefficient ^a		Thermal Conductivity ^a	
		°F	°C	lb/in ³	g/cm ³	°F × 10 ⁻⁶	°C × 10 ⁻⁶	Btu/ft ² /hr/°F/in.	cal/cm ² /s/°C/cm
Co	HCP	2723	1493	0.32	8.9	7.0	12.4	464	0.215
Ni	FCC	2647	1452	0.32	8.9	7.4	13.3	610	0.165
Fe	BCC	2798	1535	0.28	7.87	6.7	11.7	493	0.175

^a At room temperature.

Source: From *Superalloys II*, Wiley, 1987, p. 14.

Figure 51.1: Image of material characteristics

Source: Kutz, M. ed., 2002. Handbook of materials selection. John Wiley & Sons.

Template of material Characteristics

Documentation of material characteristics

1. Name of characteristic

- Properties
 - Unit of property
 - ...
-

Sources

OpenNext work project results: Section [78.1](#)

52 Software and Firmware architecture

The software architecture represents the repository details of all the software and firmware that is necessary for reusing and running the project.

See Chapter 49 for information about how to document this. Provide both an image and the editable files, as well as instruction how to use them.

52.1 Details

Please provide :

- Clear installation guide
- Description of programming algorithm
- The source code
- Version of software and its dependencies (both hardware and software dependencies)

2. Documentation of different parts of software

Examples:

[Nasa-JPL](#)*

[AmboVent](#)*

[Poppy project](#)*

Sources

OpenNext work project results: Section [78.1](#)

53 Electrical architecture

The architectural structure is a physical or logical layout of the components of a system design and their internal and external connections.

1. What minimum documentation should the architectural structure provide?
 - A model specifying the kind of components and their sub-components in the format of a tree or a graph including
 - DC motor
 - A/D converter
 - DC converters

 - Rotor
 - Sensor system
 - Motherboard
 - kit
 - Resistor
 - Transistors
 - IC
 - Sensors
 - Etc.

See @sec-structural-model for information about how to document this. Provide both an image and the editable files, as well as instruction how to use them.

example

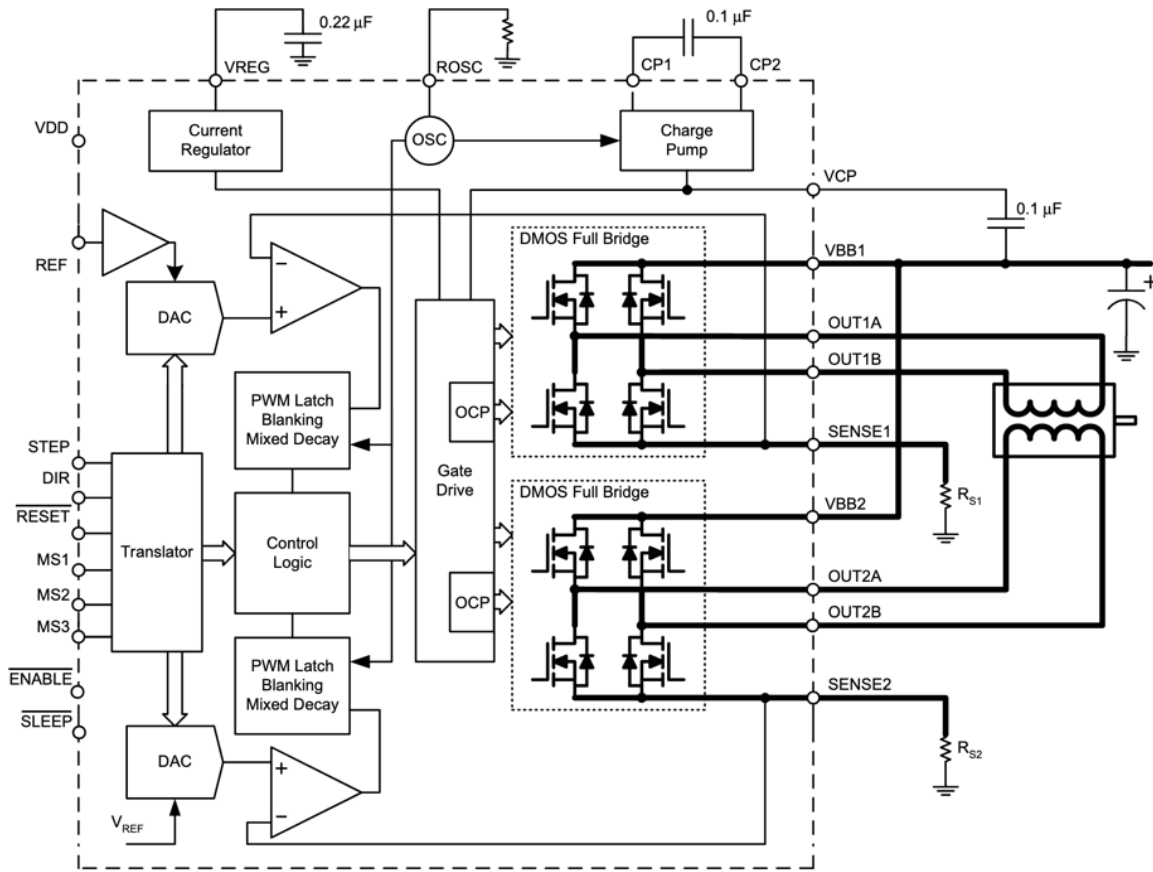


Figure 53.1: Image of Structural graph of Open-Source-Ventilator

53.1 Details and editable format: PCB design

To reuse a electrical design, it should provide information consist of:

1. Preferable file format
 - Editable file formats that could be:
 - Source formats such as .gbr, .lib format
 - Neutral formats such as Kicad_mod, kicad_pcb
2. Preferable open-source software
 - Tiny CAD

- KiCAD
- ADINA

Examples:

[Nasa-JPL, source files](#)*

[AmbovVent, Neutral files](#)*

Sources

OpenNext work project results: Section [78.1](#)

Part VI

Project history

54 Project history -changelog.md

55 Project history - release notes

56 Project history -design choices

Part VII

user guides

57 Guide for Users

I would like to provide important information to end-users on 'how to use my product'.

57.1 What is the user guide?

The user guide consists of information that allows end-users to operate the product properly. This may includes information on setting the hardware, operating the hardware, recognizing and solving problems, run the maintenance of the hardware and dispose of the hardware when it is beyond repair. The user guide is written for non-technical people.

Note the user guide may link to other parts of the documentation (especially for installation instruction/first use instructions), or even to specific online help (for troubleshooting, a forum may be indicated on to of “usual problems”). It usually includes:

1. Description of the device :Chapter [59](#)
2. Safety information: Chapter [58](#)
3. Use of the product: Chapter [60](#)
4. Calibration instructions: Chapter [62](#)
5. Troubleshooting section: Chapter [61](#)
6. Environmental management: Chapter [67](#)
7. Maintenance and Repair information: Chapter [65](#), Chapter [63](#)
8. Disposal information: Chapter [66](#)

57.2 How to create a user guide ?

The form of the guide is usually a printable document or a website. It is advised to use markdown file for its creation and deliver a printable pdf for the users. The use of screenshots, photos and videos are usually welcome.

Some popular software used to create webpage and pdf from markdown files:

- [GitBook](#)
- [readthedoc](#)
- [quarto](#)
- [Gitbuilding](#) can also be used to this purpose.

Some examples of open-source projects that show the user guide.

[PSLab oscilloscope](#)

[PX4 vision userguide](#)

[Echopen project](#)

[Poppy project](#)

[FarmBot Genesis V1.5](#)

Sources

OpenNext work project results: Section [78.1](#)

58 User Guides : Safety information

59 User Guides - Overview of the hardware

including:

- Device name (and its parts) and their definition
 - Essentials and technical specifications
-

Sources

OpenNext work project results: Section [78.1](#)

60 Operation instructions

The operation instruction gives information on the use of the product, in particular in term of software. Note that it may include the calibration chapter (Chapter [62](#)) when calibration is necessary for each use.

It may includes

- Materials required
 - App
 - Software
 - Firmware
- Procedure
 - Installation instructions including
 - * Firmware installation
 - * Software installation
 - * App installation
 - Setup instructions containing
 - * Software setup
 - * Firmware setup
 - * App setup
 - Explains how to update the firmware to the latest version

Sources

OpenNext work project results: Section [78.1](#)

61 User Guides: Troubleshooting

61.1 Testing instructions

The user guide should give information on methods to test the accuracy of the hardware. This may include specific data to give the hardware as input and some information about how to interpret the quality of the output.

Example: Ink Printers usually have a testing mode where a specific data file is used where the printed output will inform the user about the accuracy of the printer. The guide then explain what users should look for in order to make a diagnostic.

61.2 Troubleshooting

- Instructions on how to solve common problems
- Instruction to get additional help and report problems (Git forge issues, forums, chat,...).

Sources

OpenNext work project results: Section [78.1](#)

62 User Guides: Calibration

63 User Guides : Repair

63.1 Identifying the defective components

This can be linked to scheduled tests, or be done when an issue is seen. The guide should answer these questions, it may be written as a table:

- How to monitor the performance of the equipment? (what additional equipment may be necessary for this monitoring)
- How to detect a defective component, and determine what is defective ?
- How to eliminate the fault (see below) ?
- How to verify that the fault was eliminated

63.2 Repairing the defective components

For each element which may be defective:

- Step-by-step procedures describing the repairing sequence
- Refer to the technical documentation where you can find the manufacturing (and assembly) instructions to rebuild the defective components
- Indicate the required tools for repairing
- Verification of repair
- It may be interesting to add images and photos.

Sources

OpenNext work project results: Section [78.1](#)

64 User Guides: Replacing equipment components

This is very similar to the repairing section Chapter [63](#), even if this is planned modifications.

- Links to step-by-step procedures describing the replacing sequence.
- Required tools for replacing the components

Example

Replacing Ink cartridge in a printer or a lamp bulb in a video projector.

Sources

OpenNext work project results: Section [78.1](#)

65 Maintenance

Maintenance instructions provide the necessary information to maintain the system effectively and perform the required operations to system works properly in the long run. This includes advice on the frequency of the maintenance and the risks of failure.

It may also include information on the process of modifying a system or component after delivery, in order to correct faults, improve performance or other attributes, or adapt to a changing environment.

65.1 Maintenance instructions

A maintenance instruction is a technical communication document intended to give recommendations and necessary information to maintain the system effectively. In this book, we treat the identification of defective components and their repair as separate tasks, while others have defined it as part of the maintenance.

Note that the instructions are meant for the users and should therefore be focused on the schedule of maintenance. The maintenance information (what to do) may be directed toward experienced/professional people. In addition, this latter (technical) information may be best linked to the technical documentation of each part, in order to avoid giving outdated information (for example giving repair information for version 1, while the rest of the documentation is for version 2 of a hardware).

The maintenance user guide may include:

1. Introduction of general maintenance
 - Cleaning
 - Lubricating
 - Regular inspections or services. These can be carried out on a time-based schedule or a usage-based schedule. See also [Chapter 63](#):
 - Maintenance according to predetermined intervals
 - Maintenance according to prescribed criteria
 - Maintenance by integrating analysis, measurement, and periodic test activities
 - Regular adjusting machinery
 - Maintenance tools (Various tools necessary to perform the maintenance operation)

- Schedule for Replacing equipment, see also Chapter [64](#)

examples [FarmBot Genesis V1.5](#)

Template of maintenance

Common procedures: - cleaning - lubricating - machine adjustments - calibrations - (periodic) test activities

Information to give: - predetermined interval - prescribed criteria - tools - verification procedure

Sources

OpenNext work project results: Section [78.1](#)

66 Disposal instructions

Disposal instructions identify the process of removing a system or its component, ensuring the proper handling of any environmentally sensitive materials, and sending the remainder to surplus storage or sale.

They describe each component with information about their end of life (depending on their material content). Each element will be classed corresponding to their “recyclability”, and information is given to reduce the negative environmental impact of the disposal and recycling of the hardware component.

Classing elements

Recyclable: waste which can be turned into another form of new and reusable materials without specific treatment.

Non-recyclable: the components or products that designed for single-use, which means they get discarded immediately after use.

Conditionally recyclable: component which needs specific treatment before being recycled.

- Distinguishing the recyclable, Conditionally recyclable and Non-recyclable components or products.
- Determining what material can be recycled many times
- Identify the product lifespan for disposing and/or recycling.
- Describe how to recycle the components or products and their type of materials?
- Describe how to dispose of components which cannot be recycled.

Disposable products are most often made from Polystyrene and Cotton, Non-recyclable products from Textiles and Ceramics.

Types of disposal:

- Incineration: This type of waste disposal involves the dumping off method where you eliminate waste materials via combustion.
- Landfill: It involves collecting, transporting, dumping, and burying waste in a designated land.

disassembly

Indicate how to disassemble the components a product for recycling/disposing?

environmental assessment

it is the assessment of the environmental consequences of disposing or recycling a product before the decision to move forward with the proposed action. - The negative consequences of disposable products on the environment if sustainability isn't factored into disposal options. - How to select the disposal or recycling process to have a less environmental impact?

Template of disposal

For each element or part, indicate:

- sub-part name
- parent part number and name, with links
- link to disassembly instructions (see sec-product-build-assembly-instructions)
- material used + how many times can it be recycled
- recyclable (yes/no/conditional)
- disposition information, for each option:
 - how to
 - environmental assessment of disposal options:
 - * described the negative consequences of disposal
 - * Define and describe the main parameters and processes to decrease these negative environmental impacts
- end of life information

Sources

OpenNext work project results: Section [78.1](#)

67 User guides: Environmental management

- Protection against weather conditions - Determining the acceptable temperature range
-

Sources

OpenNext work project results: Section [78.1](#)

Part VIII

Product build

68 Hardware production

Production instructions mean full description and instructions concerning raw material, operating conditions, and process to be employed for the manufacture and assembly of the product. This includes also skills and tools needed for manufacture and assembly.

Production usually starts with the sourcing of material, and a bill of material (BOM) is required. It describes all the components and their references. If the component is to be purchased, one should find all the information required to buy the part. If the part is to be manufactured, one should find all the descriptions of the manufacturing instructions, as well as all the components needed for this manufacture (for instance, The BOM should report the amount of PLA needed when parts are 3D-printed).

68.1 Production instructions should include:

- A bill of material (BOM): it gives an overview of all the material that needs to be sourced and/or manufactured, and describes all the components and their references: [Chapter 69](#)
- Manufacturing information: they can guide the makers to follow a process for replicating a product, and mean full description and instructions concerning raw material, operating conditions, and process to be employed for the manufacture of the hardware parts.
 - Manufacturing skills needed: [Chapter 73](#)
 - Manufacturing tools needed: [Chapter 74](#)
 - Manufacturing sequences: [Chapter 75](#)
- Assembly instructions: they can guide the makers to follow the process of assembly or disassembly of components of a product, and illustrate visually and with words and text how to assemble or disassemble the mechanical and electrical components of the product.
 - Assembly tools and skills needed: [Chapter 77](#)
 - Assembly sequences: [Chapter 76](#)
- If relevant, the electric and electronic plan should be provided ([Chapter 71](#)). Note that firmware and software installation (described at [Chapter 72](#)) may be included in the assembly sequence.

68.2 Helping workflow and software

It is sometimes easier to create a guide for manufacturing and assembly. For instance, using the Gitbuilding software, one can write the manufacture and assembly instructions, and when using specific tags for tools and material, the software creates BOM, part lists and tool lists for each step and for the whole project.

Sources

OpenNext work project results: [Section 78.1](#)

69 Product Build: Bill of material

A bill of materials (BOM) is a comprehensive list of parts, items, and other materials required to create a product, as well as instructions required for gathering and using the required materials. If the component is to be purchased, one should find all the information required to buy the part. If the part is to be manufactured, one should find all the descriptions of the manufacturing instructions as described below.

A bill of material usually includes:

1. Part number
2. Item name
3. Manufacturer part number
4. Digi-Key part number
5. Description
6. Manufactured part (link to manufacturing instruction)
7. Purchased part (link to seller website)
8. Quantity
9. Price
10. Manufacturing standard lead time
11. Packaging instruction
12. BOM notes

69.1 Modularisation

When there are multiple parts, it is best practice to have a BOM for each part, and one BOM for the whole hardware. For complex project, it is therefore best to create BOM automatically. Some software are meant to create BOM from the CAD files (CAD-coupled documentation, <https://doi.org/10.5334/joh.56>) or from the assembly instruction (using [Gitbuilding](#)).

Example

Example 1: JPL Open Source Rover

1	Manufacturer Part Number	Manufacturer	Digi-Key Part Number	Customer Reference	Reference Designator	Packaging	Part Status	Quantity	Unit Price	Extended Price
2	3169	Adafruit Industries LLC	1528-1737-ND			Bulk	Active	2	4.95	\$9.90
3	3166	Adafruit Industries LLC	1528-1734-ND			Bulk	Active	2	4.95	\$9.90
4	3167	Adafruit Industries LLC	1528-1735-ND			Bulk	Active	2	4.95	\$9.90
5	3168	Adafruit Industries LLC	1528-1736-ND			Bulk	Active	2	4.95	\$9.90
6	LM358P	Texas Instruments	296-1395-5-ND			Tube	Active	10	0.367	\$3.67
7	76512.18.01	General Cable/Carol Brand	C76512B-50-ND			Bulk	Active	2	15.59	\$31.18
8	1569-20-1-0500-001-1-TS	CNC Tech	CN538B-50-ND			Spool	Active	2	11.92	\$23.84
9	76512.18.03	General Cable/Carol Brand	C76512R-50-ND			Bulk	Active	2	15.59	\$31.18
10	1569-20-1-0500-004-1-TS	CNC Tech	CN541R-50-ND			Spool	Active	2	11.92	\$23.84
11	PRPC040SAAN-RC	Sullins Connector Solutions	S1011EC-40-ND			Bag	Active	10	0.592	\$5.92
12	C3900BA	Bulgin	1091-1026-ND			Bulk	Active	1	4.49	\$4.49
13	3165	Adafruit Industries LLC	1528-1733-ND			Bulk	Active	2	4.95	\$9.90
14	3164	Adafruit Industries LLC	1528-1732-ND			Bulk	Active	2	4.95	\$9.90
15	CF14JT4K70	Stackpole Electronics Inc.	CF14JT4K70CT-ND			Cut Tape (CT)	Active	10	0.04	\$0.40
16	CF14JT10K0	Stackpole Electronics Inc.	CF14JT10K0CT-ND			Cut Tape (CT)	Active	25	0.0288	\$0.72
17	CF14JT22K0	Stackpole Electronics Inc.	CF14JT22K0CT-ND			Cut Tape (CT)	Active	25	0.0288	\$0.72

Figure 69.1: JPL BOM

Example 2: SatNOGS Rotator v3

Example 3: Krab v1.0

Sources

OpenNext work project results: Section [78.1](#)

70 Product build -material characteristics

71 Product Build: Electrical design

Datasheet of components for electronic parts:

- Description of features
 - Core
 - Memories
 - Advanced connectivity
- Device summary
 - Reference
 - Part number
- How to use the parts?

Sources

OpenNext work project results: Section [78.1](#)

72 Product build -firmware/Software

Here comes the elements that were more briefly described in Chapter 52. Since software/firmware development follows different practices that often needs a more detailed version control system, they are usually developed independently of the hardware.

In all cases, it is important to keep track of which version of the soft/firmwares are used with which version of the hardware.

Example: the airtrack hardware: <https://codeberg.org/openmake/airtrack-hardware>, software: <https://github.com/open-make/code-airtrack>

The Airtrack hardware was developed using pixycam. The hardware and the software are developed in different repositories with different people involved. In 2025, as the pixycam was not produced anymore, a new version of the hardware was created, using the pixycam2 component. This had little effects on the hardware design, but, the firmware and software needed to be modified.

Sources

OpenNext work project results: Section 78.1

73 Product Build: Manufacturing skills

What is the specific knowledge a maker shall own to manufacture the different parts of the hardware ?

74 Product build: Manufacturing tool

Manufacturing tools means all the machinery, equipment, and processes used to manufacture products. Manufacturing technology guide to find the type of necessary technology to produce the part. In that case, it should describe the most suitable technology according to the context.

74.1 Type of machines

Type of machines used

1. CNC machine tools for machining metal or other rigid materials
 - Milling
 - Lathe
 - Cutting
 - Drilling
2. Other common manufacturing tools
 - 3D printing (FDM, SLS...)
 - Thermoforming
 - Burning machining technology (laser cutting, Plasma cutting, ...)
 - Bonding technologies (Solder, cold welding, arc welding, adhesive bonding ...)
3. Finishing: to achieve the right properties such as surface quality, geometrical accuracy, and mechanical properties, finishing is essential.
 - Sanding after 3D printing
 - Gap filling
 - Blasting
 - Polishing
 - Priming and painting

Examples

[JPL Open Source Rover](#)

[SatNOGS Rotator v3](#)

Sources

OpenNext work project results: Section [78.1](#)

75 Product build: Manufacturing sequence

The Manufacturing sequences refer to step-by-step machining and manufacturing processes in a target-oriented arrangement to enable manufacturing.

- The machining sequence should define for the manufacturing of each part.
- Process parameters are all those parameters that are inherent to any machining operation
- Manufacturing standard file formats support some of the manufacturing processes and tools

75.1 What does include the documentation of manufacturing sequences and instructions?

1. Name of the related machine of each step
2. Describing step by step sequence of the machining process - Machine - Type of operation
 - Tools description - Process parameters of each machining operation
 - Process parameters of 3D printing
 - Process parameters of Laser cutting
 - Process parameters of CNC machines such as Lathe, Milling, etc.
 - Process parameters of arc welding
 - Raw material (including size if relevant)
 - Manufacturing files (STL, SVG or G-code, ...)
 - CAD files in an interchange format such as STL that is suitable for 3D printing
 - Nominal geometry and its allowable variation by using symbolic language on 2D drawings like SVG, JPEG, and PDF format that is suitable for laser cutting
 - Manufacturing export formats such as G-code, STEP-NC is suitable for CNC machining
 - Circuit board design formats such as Gerber RS-274X, excellon that is suitable for vector photoplotters 2D mechanical NC machines

Examples

Machine	Type of operations	Tools	Parameters	Unit	Value	Raw material	File	Image
3D printer	Print	Nozzle guide	First layer height	mm	2	PLA	link to STL file	
	Print	Nozzle guide	First layer speed	mm/s	3	PLA	link to STL file	
CNC machine	Drilling	Drill	Depth of cut	mm	8	Steel	CAD file	
	Milling	HSK milling cutter	Cutting speed	mm/s	4	Steel	CAD file	
Machine 3								

Figure 75.1: image of manufacturing sequence

[JPL Open Source Rover](#)

[DIY Dremel CNC design and parts](#) and [its CAM file for machining](#)

[SatNOGS Rotator v3](#), [2D drawing file](#)

Note: types of CAD format of [transmagic](#)

75.2 Example of parameters

1. 3D printer parameters

- Extruder setting
 - Extrusion multiplier
 - Retraction distance
 - Retraction speed
 - Coasting
- Layer setting
 - First layer height
 - First layer speed
- Laver height
- Printing bed temperature

- Infill setting
 - Internal/Eternal fill pattern
 - Temperature setting
 - Cooling setting
2. CNC machines parameters such as Lathe, Milling, etc.
- Cutting parameters
 - Cutting speed
 - Feed rate
 - Cutting depth
 - Cutting width
 - Cutting force
 - Spindle speed
 - Cutting temperature
 - Cutting tool
 - Tool Geometry
 - Tool setting
 - Coolant
3. Burning machining parameters such as laser cutting
- Beam parameters
 - Wavelength
 - Power and intensity
 - Polarization
 - Process Parameters
 - Focusing of laser beams (the focal length of the lens)
 - Focal position
 - Angle of incidence
 - Cutting speed
 - Gas pressure
 - Stand-off distance
 - Expected duration
4. Bonding technologies parameters such as Arc welding
- Welding current
 - Welding voltage
 - Arc travel speed

- Torch angle
 - Longitudinal
 - Transverse
 - Electrode force
 - Electrode diameters
 - Length of arc
-

Sources

OpenNext work project results: Section [78.1](#)

76 Product Build: Assembly sequence

The Assembly sequence usually start with a description and list of each part that will be assembled, and then provide a step-by-step guide. One can think of instruction for lego objects (In these special case, the part list is identical to a BOM and placed at the end).

See Chapter [68](#) for information about software and dependence with guide for manufacturing.

76.1 Part list

The Part list for mechanical parts is a complete list of all parts needed to build the complete product. It is different from the BOM which list material needed for the manufacture of the parts, while this document list the manufactured parts.

It constitutes of : - Item numbers: are based on the assembly structure, that is, the order in which parts are displayed in assembly. - Part number or drawing number: which is a reference back to the detail drawing (refer to the BOM). - Description: is usually a part name or a complete description of parts. - Quantity is the number of that particular part used on this assembly. - Image (or STL render) of each part.

76.2 Sequence

The set of steps necessary to properly assemble the parts should be well described at each step.

- The joining technology at each step should be clearly described: - Screwing - Bolting - Soldering - Gluing (or “gluing and screwing”)

Example

[Poppy Robot](#)

[JPL Open Source Rover](#)

[SatNOGS Rotator v3 , Assembly instructions](#)

[Open Source Powered Prosthetic Leg](#)

76.3 Notes

It is good practice to design the parts such that the assembly is easier. One can for instance include the item number on the parts and make sure that it is difficult to assemble parts at the wrong step, for instance by designing asymmetrical parts.

Sources

OpenNext work project results: Section [78.1](#)

77 Product Build: Assembly skills and tools

This document should provide information about the specific knowledge a maker shall own to assembly the hardware product, and what tools are necessary. For example, one can report how many people are needed to assemble the hardware.

77.1 Example of skills and machines:

1. Required skills for assembly
 - Operate drilling machine
 - Operate Band Saw/Dremel
2. List of the tools for assembly or disassembly
 - Mandatory
 - Allen Keyset
 - Imperial wrench set
 - Optional
 - Drill press

The skills can be listed by name and a description. In many case, it might be interesting to link skills with tools, as being able to operate each tool is a needed skill.

Example

To build the Airtrack, it is optional to use specific UV glue and its specific equipment. One should nevertheless have some experience in using plastic glue.

Sources

OpenNext work project results: Section [78.1](#)

78 Sources

78.1 Open next work