Engineering

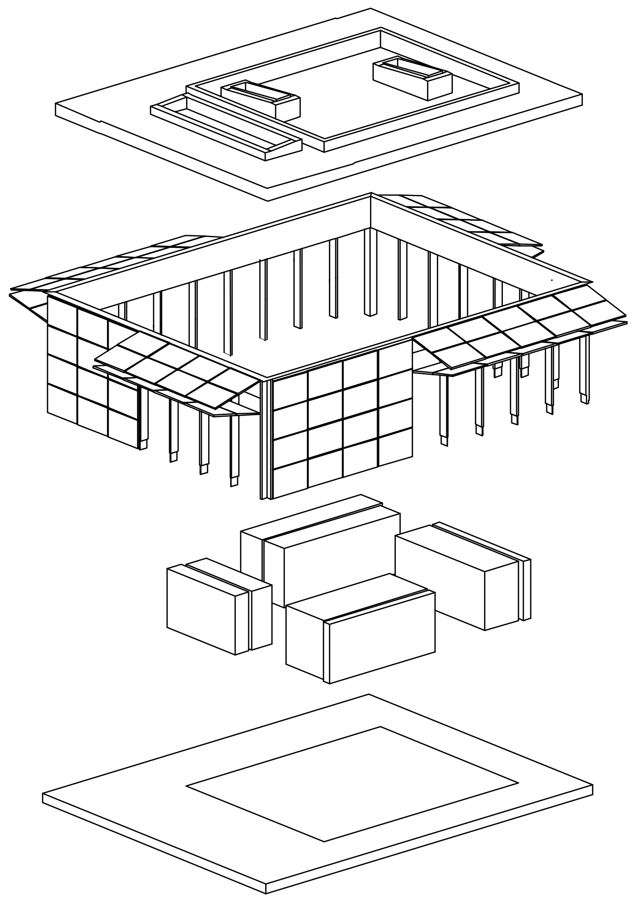
Introduction

The Swiss Team believes that the transition towards a more sustainable world through the development of greener technologies has already begun, but that local communities need to play a stronger role as change leaders. Our mission is to be a catalyst of sustainable changes in our everyday habits. The answers to environmental and social challenges do not lie in building an energy-efficient single-family house in a residential area.

We need more: The NeighborHub.

We have created the NeighborHub, a socio-technical infrastructure located in a suburban area, which aims to act as a platform diffusing knowledge about sustainable practices within the community. The house showcases innovative and low-tech solutions about which the users are encouraged to learn and discuss during community events such as workshops. The objective is to provide residents with tools for adopting more sustainable practices through a learning-by-doing approach.

Our engineering design was conceived through very close interaction between the architecture and engineering students, allowing the Swiss Team to answer the challenges of a modular and integrated building for the community.



[1] Break-down of the NeighborHub

One multifaceted building

The NeighborHub

The NeighborHub combines two key zones: a Core and an Extended Skin.
They rely on an efficient combination of passive and active strategies and an innovative construction design.

The NeighborHub is made of different building elements superposed on each other **[1]**. Four prefabricated modules containing the building's facilities make up the Core. They provide a kitchen, bathroom, bedroom and closets which create a living area for the neighborhood where users can cook, work or sleep.

This key space is surrounded by the Extended Skin, a semi-exterior area protected by a fully-integrated solar envelope allowing inhabitants of a neighborhood to perform various activities.

The NeighborHub is made of one raw sustainable resource: wood, a multifaceted material which combines several functions.

As a structural element, wood is one of the best materials for a prefabricated and flexible design.

One multifaceted building

A prefabricated design

The NeighborHub is an effective traveller thanks to our prefabricated design. The building requires a well-thought-out constructive design, for both its journey to the United States and to withstand the numerous times it will be assembled and disassembled.

To achieve this, each module of the NeighborHub was designed to be transported unaltered in an international standard shipping container **[2]**. Every component has been prefabricated in Switzerland, out of cross-laminated timber panels (Laminated Veneer Lumber). This material has good structural and mechanical properties.

On one hand, its airtightness and vapor permeability prevent mold and moisture problems without the need for any additional sealing.

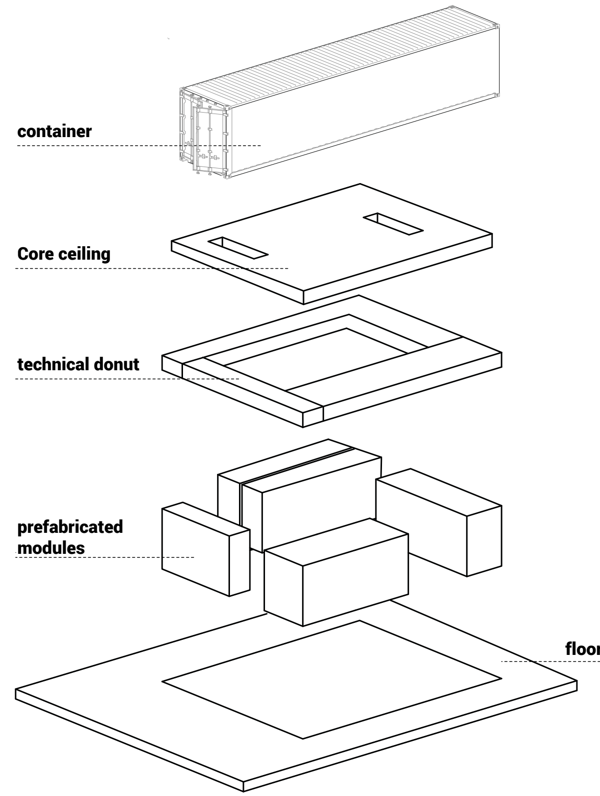
On the other, it minimizes the dimensional variation of the wood resulting from humidity variation, particularly convenient for decreasing the risk of deterioration due to transatlantic shipping conditions.

Each module of the NeighborHub is prefabricated with these panels thanks to a combination of tenon joints and structural glue. The assembling system consists of bearing-type connections and threaded inserts, which do not damage the wood and make it possible to assemble and disassemble easily.

All technical utilities are also pre-installed into the modules. This strategy guarantees installation quality, minimizes risk of weaknesses such as leaks in the modules and eases on-site construction.

The interconnections between each element are quite challenging and require the use of specific techniques for the utilities' assembly process.

We opted for easy connections such as plugs for electric cables, as well as flexible water pipes and ventilation ducts. This allows the interconnection between the modules to be speeded up during the competition but also when back in Switzerland.



[2] Break-down of the Core

Since most of the construction was completed in Switzerland, assembly time in Denver will be significantly reduced - by 85 % !

Finally, our prefabrication strategy combined with advanced structural engineering techniques strengthens the modularity of the NeighborHub.

One multifaceted building

Modular construction

What best defines the NeighborHub is its modular concept. The infrastructure needs to be able to adapt to any neighborhood and the modular layout of the Core answers this particular requirement.
Indeed, the four Core modules can be changed from one NeighborHub to another and combine different facilities, allowing the building to better fit within its environment.

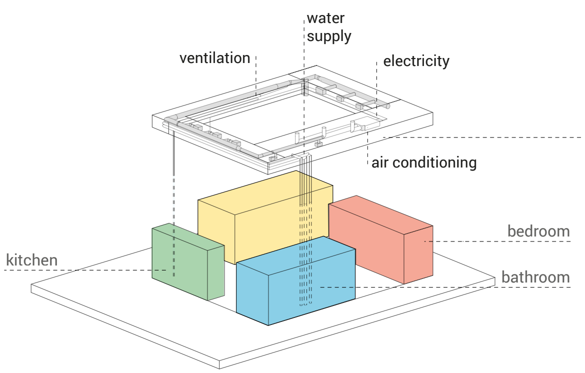
Since the modules are prefabricated, we developed a simple solution enabling us to keep the same engineering approach no matter what the layout.

A ring-like element placed on top of the four Core modules allows each module to obtain all the energy utilities needed for their respective function.
This ring, called the technical 'donut', carries electricity, water, ventilation and air conditioning all around the Core.

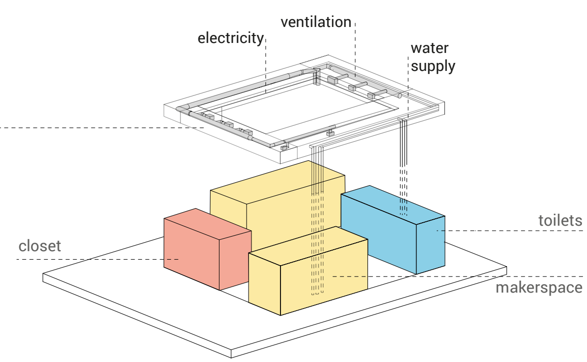
Thanks to this approach, the building's elements can keep the same prefabricated design and another layout can be chosen simply by changing the technical donut utilities distribution. Therefore, the same construction approach is maintained no matter which environment our NeighborHub targets **[3a, 3b]**.

Another approach that gives modularity to our building is the facades. The entire envelope is composed of prefabricated frames which can be equipped with photovoltaic and solar thermal panels, acrylic and polycarbonate panels.

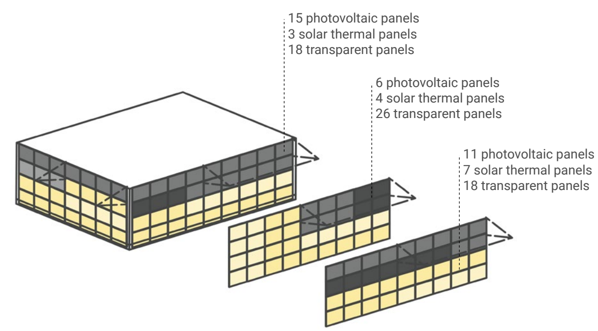
Configuration of the facade elements can be interchanged thanks to standardization of their dimensions and a complete integrated design. In this sense, the NeighborHub could be duplicated in another suburban area with different needs, and therefore adapt the composition of its envelope **[4]**.



[3a] The NeighborHub (competition layout)



[3b] A new NeighborHub (another layout)



[4] Adaptive envelope

A dual energy strategy

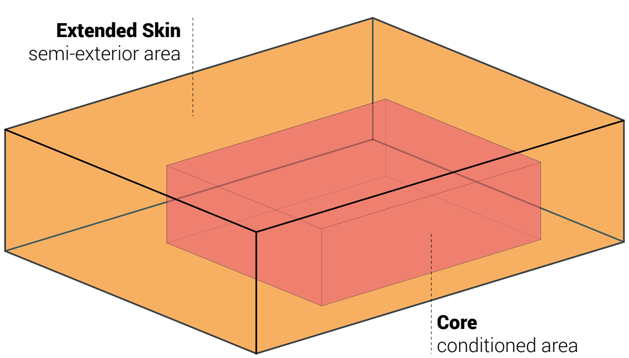
Differentiated thermal concept

The NeighborHub has an underlying comfort concept which was developed through many iterative processes. An academic course, in 2016, placed the first foundation stone for our design which was then fed with energy modeling results (EnergyPlus) and lighting simulations (DIVA). These early simulations had a significant influence on the project design, supporting and integrating passive solutions in the building.

The Core and the Extended Skin are distinguishable by the contrast between two differentiated thermal zones **[5]**.
The Core is the conditioned area that conforms to the strict regulations of the competition rules in terms of temperature, relative humidity and CO_2 levels.

However, the Extended Skin follows a different perspective regarding comfort ranges. It is a semi-exterior space, only passively controlled.

[5] Differentiated thermal concept



The Extended Skin, a passive strategy

Designing a building as an infrastructure for a neighborhood requires various comfort conditions.

Our design relies on the strategy of reducing energy consumption by not 'over-controlling' comfort conditions in the Extended Skin area. Comfort should be considered according to the activities which take place in a given space. For example, repairing a bike does not require a heated room.

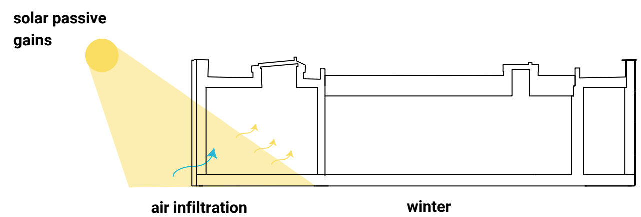
With this in mind, the Extended Skin is designed to increase the number of hours all year round during which the space is comfortable enough for the community to perform semi-exterior activities (59 to 79 °F). This space is protected by the building's facades which are composed of large foldings doors. These movable openings, combined with modular roof skylights in the Extended Skin's ceiling, provide natural ventilation and daylight input.

In winter, closing the facades maximizes the solar passive gains and allows the semi-exterior area to reach a higher temperature than outside **[6a]**.

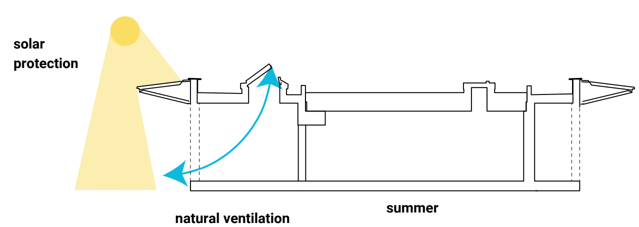
In summer, the folding doors are used to shade the space from excessive solar radiation and allow natural ventilation.

This ventilated semi-exterior space provides more comfortable conditions than outside **[6b]**.
The Extended Skin therefore offers an ideal unconditioned and well-protected area against adverse weather, for the neighborhood to perform various activities.

However the conditioned space of the NeighborHub is actively controlled to keep environmental conditions acceptable for typical indoor living requirements.



[6a] Passive strategy in winter



[6b] Passive strategy in summer

A dual energy strategy

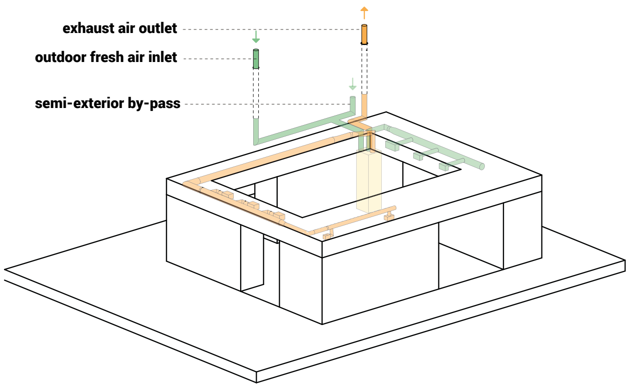
The Core, a controlled space

The NeighborHub's active systems were designed for the house in Fribourg, taking into account specific adaptations for better performance in Denver.
Air conditioning and mechanical ventilation have been completely separated, which increases their resilience as they are independent from each other. This also ensures maximum adaptability for the NeighborHub, as the air conditioning sizing can be changed to suit any climatic conditions.

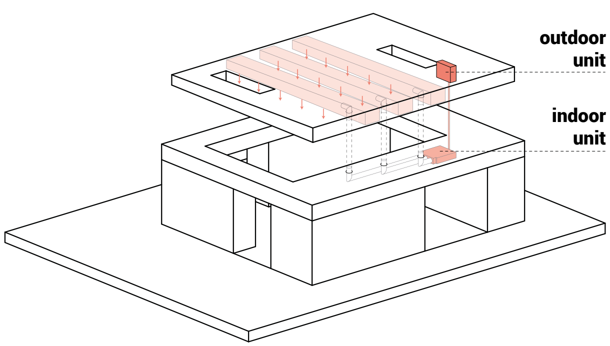
Mechanical ventilation is used to provide fresh air to the Core in order to regulate the relative humidity and CO_2 levels. Balanced ventilation equipped with an effective energy recovery system significantly reduces energy losses. Indeed, our enthalpy heat exchanger can capture up to 70 % of latent energy.

This solution allows incoming air to be preheated in winter, whereas in summer the warmer outdoor air is cooled thanks to exhaust air.
As a result, our balanced ventilation reduces both heating and cooling loads, maintains a low CO_2 level and reduces air dehumidification.

Finally, a bypass system allows the fresh air to come either from the outdoor environment or the Extended Skin, depending on the air temperature of both spaces. According to the season, such a system provides additional heat gains when the Extended Skin air temperature is warmer than outside **[7]**.



[7] Mechanical ventilation distribution



[8] Air conditioning distribution

Heating and cooling of the Core is based on a forced-air system, chosen for its compactness, simplicity of integration and thermal responsiveness.

The system is composed of an indoor unit located in the technical donut and a heat-pump unit located on the roof. Based on our simulations we designed a system providing a nominal heating and cooling capacity of 3 kW and 2.5 kW respectively.

The conditioned air is distributed through three ceiling self-bearing elements, which are used directly as distribution ducts **[8]**.

This integration is particularly innovative and highlights the strong multidisciplinary collaboration of our team. Instead of traditional vents, holes were directly drilled in the ceiling's wooden panels to supply air conditioning.

This design provides both effective distribution of air and architectural uniformity as no vents are visible.

Harvesting dynamics

Smart on-facade production

One of the NeighborHub's biggest innovation proposals is the positioning of our photovoltaic panels (PVs) on the facades. Instead of conventional roof positioning with optimized tilt, we want to showcase that other active surfaces can be the solution for more local production. The idea emerged from the Swiss context, where urban densification is currently occurring. Buildings' roof surfaces are not necessarily sufficient to cover all electrical needs, especially for high multi-storey buildings. Local production can be drastically increased if facades are used to complement classic roof installations.

With 10 kWp maximum installed power during the competition, the Swiss Team decided to focus only on the alternative of facade production to prove the viability of the concept. However, the modular design of our building and its envelope also allows panels to be added or removed. According to the specific environment where a NeighborHub could be implemented, its facade layout may vary, providing adaptability for the PV system's sizing.

Our photovoltaic system is composed of 29 panels, positioned on the East, South and West facades. A single PV has an average efficiency of 21.1% with 335 W nominal output, which gives a total of 9.7 kWp installed power.

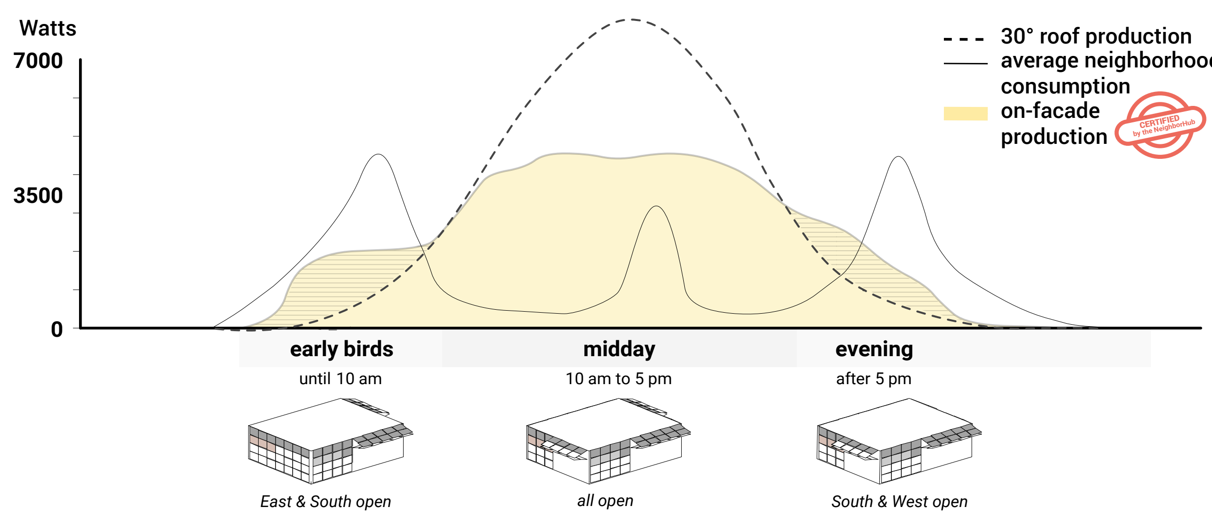
Each facade of the house has a string of PVs and combines fixed and folding doors. The same string of panels can have different tilts of 90 ° on closed doors and 17 ° when doors are opened.
This means that production may vary from one PV panel to the other and influence the overall production of the string.
For this, each photovoltaic panel is equipped with a power optimizer for maximum individual production. Thanks to power optimizers, our system is less sensitive to local shading and variable production.

In addition to having differently-oriented strings on the East, South and West facades, our combination of closed and opening doors is therefore able to provide flexibility for daily production.

As a result, our daily average production is not concentrated at midday and follows a smoother curve throughout the day. Producing efficiently requires the electrical supply to be increased in the morning and evening, when peak consumption occurs. In this sense, our local facade production with differently-oriented tilts better fits household consumption.
The NeighborHub therefore becomes a smart producer where facade openings are used to adapt their position to the sun's path and the neighborhood's needs **[9]**.

Finally, generating power in the morning and evening allows electricity to be used according to demand and reduces required storage capacity and grid extraction.

[9] Matching consumption and production



Harvesting dynamics

An energy hub for the neighborhood

The future of sustainable electrical management relies mainly on smart grid exchanges rather than self-sufficiency. Above all, buildings need to be an infrastructure working in harmony with the grid.

The NeighborHub is designed with the objective of being an electrical hub for a neighborhood. However our definition of 'hub' is a clever system aiming to help a neighborhood's electrical network reduce peak demand thanks to optimal grid exchanges.

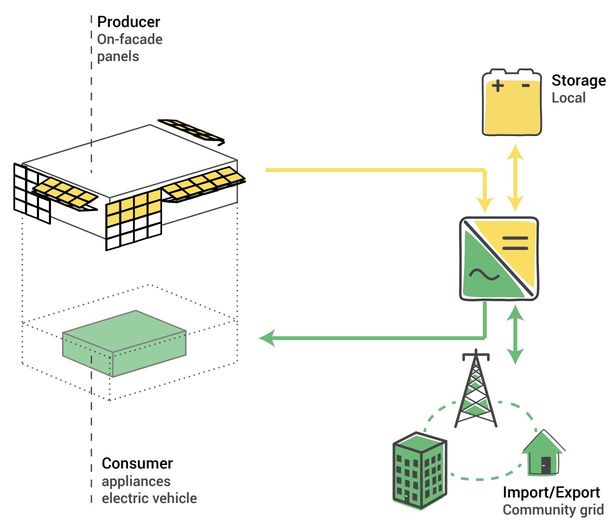
Our solution is to produce smartly rather than excessively with the objective of matching production and consumption.

To manage electrical fluxes, the NeighborHub is equipped with two household batteries of a 5.4 kWh capacity each. Having 10.8 kWh of local storage gives flexibility to the house to keep electricity available when solar production is insufficient, and uses time-shifting to compensate peak demand in the neighborhood. This local storage also provides a buffer capacity for smart grid exchanges.

Students developed algorithms in order to optimize the building's consumption and electrical balance with the grid.

To fulfill its aims, the NeighborHub uses predictive control with an objective function of maximizing grid electricity supply. The house receives airport data for daily weather forecasts and uses a weather station for live production monitoring. Thus, a 24-hour prediction horizon is used to define optimal electrical grid management while covering the needs of the house.

By combining our smart on-facade production with local storage, the NeighborHub is then able to help maintain a reliable and secure electrical infrastructure that can meet future growth demands **[10]**.



[10] An electrical "hub"

Custom-made solutions

Solar thermal panels

The innovation behind the NeighborHub concept is its learning-by-doing approach. The neighborhood's residents can discover new efficient systems and participate in creative workshops.

With this in mind, the Swiss Team developed academic courses for students to develop their own energy systems which enabled them to build the NeighborHub's facade-mounted solar thermal panels. The 90 ° inclination of the panels smooths yearly production and gives higher heat production during winter compared to the 30 ° inclined panels.

Our efficient Domestic Hot Water production relies on three solar thermal panels (51.7 ft^2 total) coupled with a heat-pump water-heater. Water is heated thanks to solar energy complemented with an air-to-water heat-pump when required.

The heat pump's air extraction is located in the Extended Skin rather than outside, maintaining a higher efficiency. Having air intake in our semi-exterior environment ensures that the heat-pump works within its optimal temperature operation range and therefore improves the system's efficiency.

Harvesting dynamics

The future of automation

The Swiss Team answers the challenge of future home automation with a custom made solution. Thanks to a collaboration with an EPFL startup, students developed an integrated control system which is the heart of the NeighborHub.

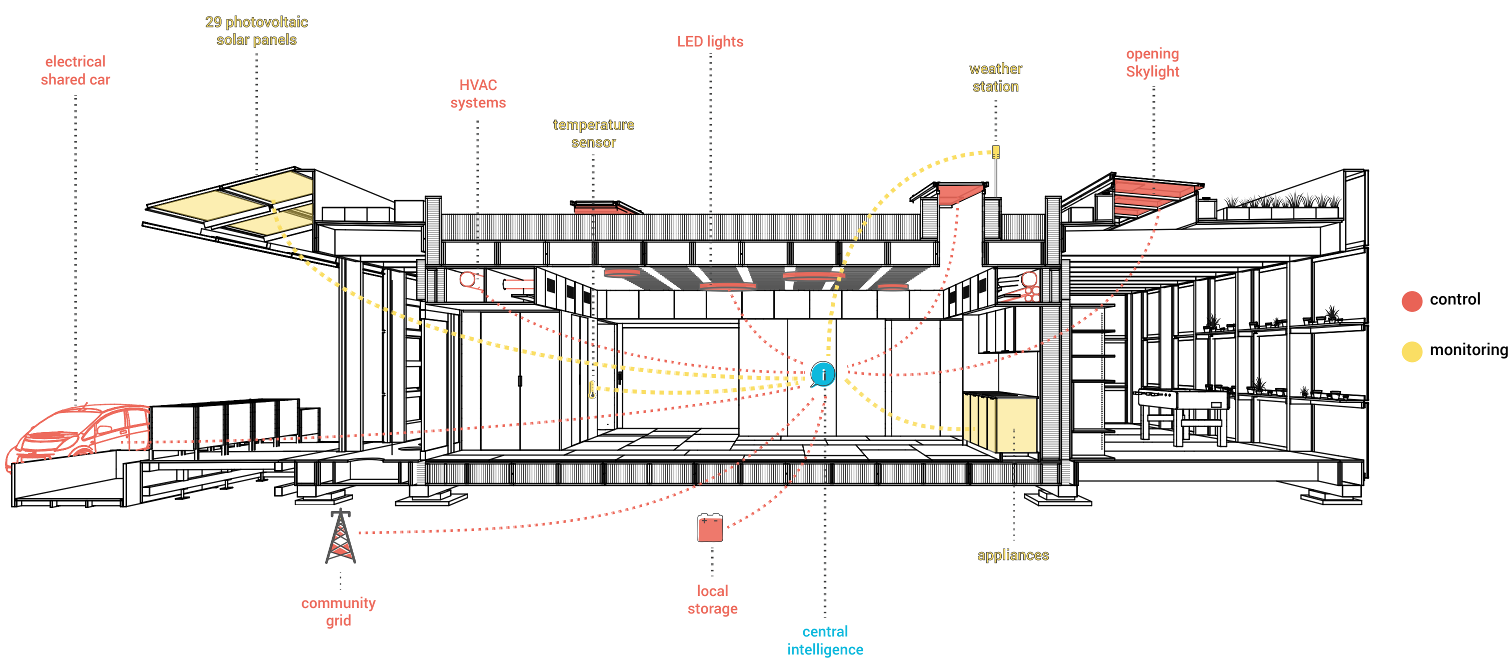
This central unit performs a software adaptation to each communication protocol of the house's devices which are usually proprietory and not accessible, allowing us to completely monitor and control the NeighborHub from a single intelligence **[11]**.

This centralized system can communicate with each device of the NeighborHub allowing them to operate together and achieve optimal performance.
Students used this central intelligence to design a complex software architecture composed of many algorithms for control and home automation.

Through real-time management and monitoring of our large range of connected devices, inhabitants of a neighborhood are able to receive real-time information about the NeighborHub's energy consumption.

For this, we have designed a user interface which puts the user, rather than the technology, at the center of the house. This interface, called " Talk to the NeighborHub ", aims to increase users' interactions with their environment, thus helping them understand more about the house's energy consumption.

The community is therefore able to witness the energy behaviour of the building through our interface providing tips and guidance to point out how to reduce the environmental impact of the NeighborHub.



[11] The NeighborHub's centralized system

Synthesis

The Swiss Team's proposition for the Solar Decathlon 2017 has resulted in a singular building.

The NeighborHub is more than a house, it is a real infrastructure designed to help neighborhoods decrease their consumption of resources and adopt more sustainable practices.

The NeighborHub demonstrates how smart changes can be adopted by communities and lead to a long-term maximization of the sustainability potential of an entire neighborhood.

Its uniqueness lies in its innovative engineering design approaches.

The Swiss Team has engineered the NeighborHub for both the local context and competition requirements.

The constructive design of the house answers the challenge of creating a modular building, that can change its layout and adapt its facilities according to the targeted environment.

Comfort in the NeighborHub is considered from another perspective, with two distinct thermal zones which provide more coherence between thermal design, levels of comfort and everyday activities.

Solar energy is harvested on the facade allowing the building to produce electricity more efficiently. Matching production to the neighborhood's needs makes our house a real hub, a clever actor, a powerful asset.

Thanks to a strong collaboration within the team, the NeighborHub embodies a highly flexible design and is composed of resilient and integrated systems.

Altogether, our design offers a productive, efficient and social building that can help to improve a neighborhood.

The Swiss Team has created not only a gathering point where the residents can learn, share and enjoy new services; but also an infrastructure that can use and optimize the energy flows of the surroundings.

It has succeeded in answering the challenge of creating a house for living together.