FUTURISTIC BEEHIVES FOR A SMART METROPOLIS

Deliverable D3.2

Hive core prototype

Lead Beneficiary	EPFL
Delivery date	30.09.2021
Dissemination Level	PU
Version	1.0
Project website	www.hiveopolis.eu

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824069

DELIVERABLE SUMMARY SHEET

Project number	824069
Project Acronym	HIVEOPOLIS
Title	FUTURISTIC BEEHIVES FOR A SMART METROPOLIS
Deliverable No	D3.2
Due Date	Project month M30
Delivery Date	30.09.2021
Name	Hive core prototype
Description	This deliverable describes the prototyping of the fully functional central core module, and includes the results of tests made using these prototypes to qualify the design of the device.
Lead Beneficiary	EPFL
Partners contributed	UNIGRAZ, BST, LLU
Dissemination Level	Public

Introduction

Purpose and scope of the document

The deliverable D3.2 presents the HIVEOPOLIS central core prototype. The aim of the central core is to provide structural, power, and data interconnectivity for the modules; to provide central computation services including data management; as well as to connect one unit to the wider HIVEOPOLIS ecosystem. This report accompanies two video compilations that provide the demonstrator portion, providing some further commentary and contextualisation of what is demonstrated in the videos.

Overview of the document

This report comprises two chapters that describe two different aspects of WP3, each one corresponding to a video that has been prepared to demonstrate the central core. Chapter 1 describes the video demonstrating the central core prototype, including provision of connectivity, docking, control and observation for the modules of a Hiveopolis unit. Chapter 2 describes the video demonstrating prototypes and progress of the repulsion/confinement system as well as the 'bee traffic control system' also developed within the remit of WP3. The links to each of these videos can be found at the end of this document.

Acronyms and Abbreviations

Acronyms and Abbreviations	**Definition**
CO_2	Carbon Dioxide
DB	Database
DSS	Decision support system
GNSS	Global navigation satellite system
TSDB	Time series database
USB	Universal Serial Bus

Chapter 1: Demonstrator video D3.2A - Hive core prototype

The central core of the HIVEOPOLIS unit connects together the modules of the hive unit, facilitates control, data logging, central computation, and additionally provides digital connectivity between the hive unit and the outside world. The core also provides some environmental sensing functionality. This video shows five aspects of the central core:

a) The process of assembling a hive unit;
b) Docking functionality;
c) Illustration of actuation control within a docked module;
d) Illustration of sensing and actuation within a docked module;
e) Physical elements in environmental sensing.

Given its wide-spanning role in interfacing with the hardware modules, the data pathways, the augmented map services, and so on, the developments of several work packages feature in this demonstrator deliverable. We identify the elements of other work packages to help clarify this (specifically, many of the modules shown are used to validate the functionality of the core side of an interaction, but clearly the efforts to develop the modules are part of other work packages).

The subsequent sections of this chapter describe the segments of the video D3.2A in further detail.

Assembling a Hiveopolis unit

This segment illustrates the steps involved in assembling a hive unit, starting from the base central column (see Fig. 1). The core electronics, including the interfaces to the modules, are contained inside the central column of the hull designed within WP2. We introduce several modules, docking each one physically, and with power and data. The types of modules illustrated occupy “bee-spaces” and “tech wedge spaces”, including:

- a brood nest frame (developed as part of WP5), wholly in a bee space;
- a dance inhibition comb (developed as part of WP4), which comprises a frame in a bee space, and driving electronics stages in a tech wedge;
- A traffic measurement module (developed as part of WP3, see more details in video D3.2B), in a bee space;
- An environmental monitor node (developed as part of WP3); this wireless node occupies a small volume in order to be flexible in mounting location - here it is shown mounted in a tech wedge.

The power is delivered into the central core, and then redistributed to the modules. Here it comes from a lab bench power supply, as a stand-in for the HIVEOPOLIS power module currently under development in WP2. Power is delivered from the feeder space of the hive, which is the candidate area for the power module.

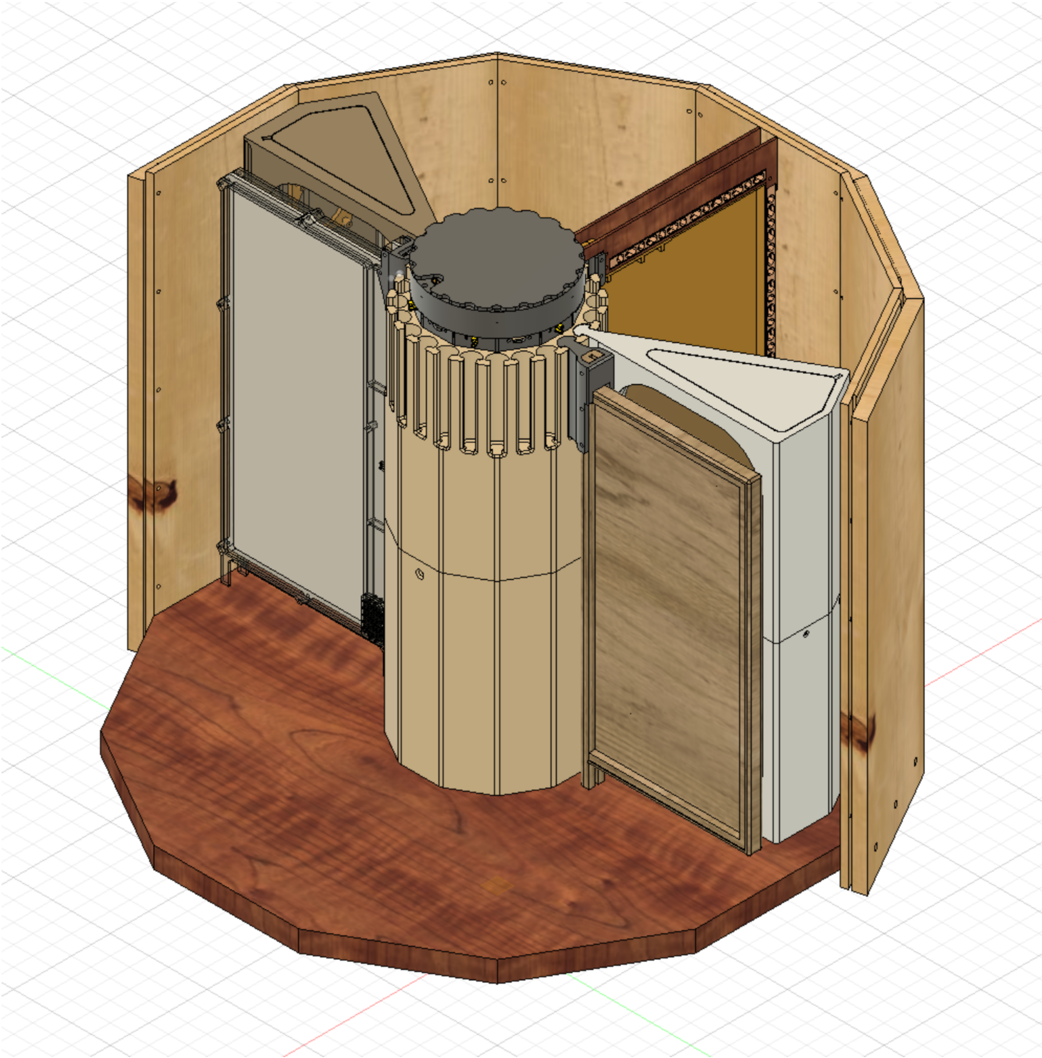


Figure 1: 3D render showing the hive hull (WP2), the central column (WP3), and several docked modules: a dancefloor vibration module (WP4), a broodnest comb module (WP5), a traffic module (WP3), and an additional tech wedge (WP2).

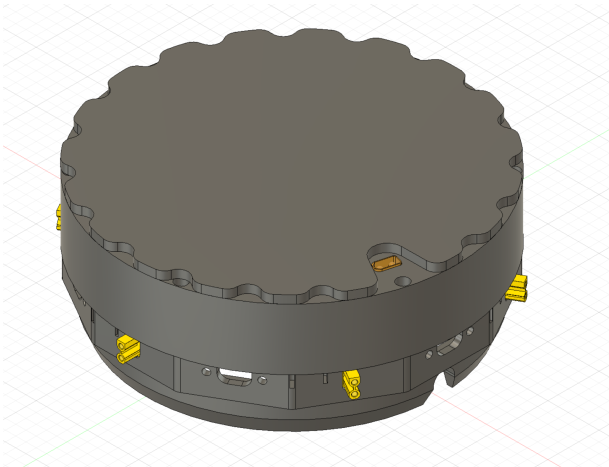
Docking functionality

This video segment takes a more detailed look at the docking functionality. The objectives from the module perspective are to receive data and power, and be physically secure in an appropriate location. From the perspective of the central core, the goal is also to be aware of which modules are attached and where. The video shows:

- The dancefloor module being docked in unsuitable locations, and the core generating warnings; when this module is placed in the correct location it is accepted (the physical docking locations are symmetric, but the dancefloor module must be located at the entrance. The green label on the core shows the correct orientation/location for the entrance).

- A broodnest module being docked in one of the flexible locations. Indeed, where the dancefloor was refused, the broodnest is docked without issue. A full hive will feature multiple broodnest frames and multiple storage modules, with the number and composition changing through the season to reflect the bee colony's size and needs. The broodnest module's serial number is also identified for traceability.
- A traffic measurement module being docked in another one of the flexible locations. In general, modules receive data and power separately, using USB-C connectors for data and AMASS XT30 connectors for 12V power supply (Fig. 2). However, since this element only uses sensors (no actuators) and hence has a low power consumption, it can operate solely via the USB connection.

The raw data from the module map enters the core database and will be presented visually by the graphical interface for individual hive units, being developed in WP2.



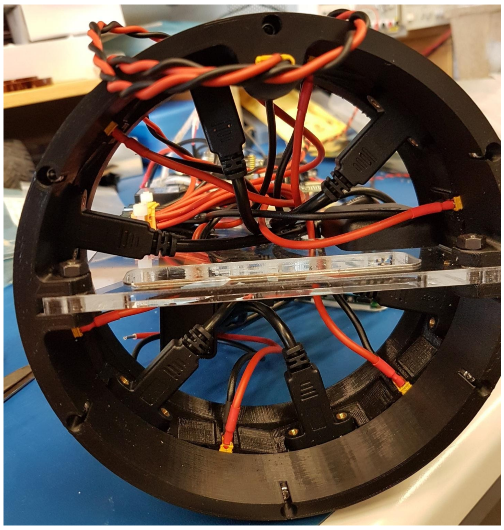


Figure 2: The docking ring element of the central core column. Left: 3D render, showing the connectors and also the groove used to correctly orient the central core insert. Right: showing the assembled prototype.

Illustration of actuation control within a docked module

In this video segment, we highlight the control of the actuations at a high level from the core over a specific module: the vibrational dancefloor, developed as part of WP4. The dancefloor module comprises two main components, the signal generation board that is located inside the wedge, and the vibrational frame, which directly interacts with honeybees. The two parts communicate via a flat cable that transfers the generated signals to the actuators located in the dancefloor. The present iteration of this module is powered with both USB (5V) and cables (12V) from the core.

In the demonstration video, we show how vibrations are triggered from the core, via wifi. The core hosts an MQTT broker that is part of the core system for wider communication, including for cloud services and multi-hive scenarios. The broker is also available for local communication and is used here as a transport platform to publish/subscribe messages between itself and the modules. The dancefloor module subscribes to the `ho/cmd/dancefloor` sub-topic of the MQTT broker, to be advertised with the different messages that are relevant for it. The core then can publish messages that the module can read. Those messages are of the form: `play scenario <n> at t=<time>`. The different scenarios (sequences of commands to be applied to the signal generation board, internal to the dancefloor module) are stored locally in the dancefloor module and can be played following the reading of such a message. As a feedback mechanism, the module publishes messages via the broker under `ho/exptmon`, such as `play start` or `play stop`, in order to indicate to the core when a new scenario can be played, or if a specific problem occured. This uses the primary topics `ho/exptmon` for high-level information. The low-level information is kept within the module, but can be transmitted to the core under primary topic (`ho/actuator`).

The core controls the modules directly; in the longer term the commands will be generated by the decision support system (DSS), which will be finalised later in the project. Thus, here we manually log into the hive, to locally trigger the scenarios. For detailed exploratory scientific experiments this local, manual mode may also be the most appropriate, to provide the experimenter a high level of detail in terms of module status and control. The second supported mode of control is via the user dashboard which will generate commands sent over the `ho/cmd` topic (addressed to specific hives where the user has appropriate privileges). The designed software uses a bridge between the cloud broker and each hive’s broker, to translate between local and external domains automatically. This results in messages from either control mode transparently realising commands via the core.

Illustration of sensing and actuation within a docked module

The electronic broodnest frame was developed as part of WP5, aiming to sense and modulate bee's thermoregulatory behaviors. These important behaviors are found in different aspects of the colony like cooling down the hive, through fanning, or regulating the brood nest at very precise temperatures to allow the development of healthy bees. This robotic frame should be able to be installed in almost any place of the HIVEOPOLIS hive and provide a logical interface to be controlled by the central core (or other modules via the central core). These capacities are demonstrated in the video D3.2A, depicted through (a) the installation of the electronic frame at different docking points of the central column, (b) connection to the hive communication network and power bus, (c) and the activation of thermal actuators (shown with the aid of a thermal camera) and collection of thermal sensors data coordinated by the central core system software (visualized in the central core time series database - InfluxDB, Fig. 3).

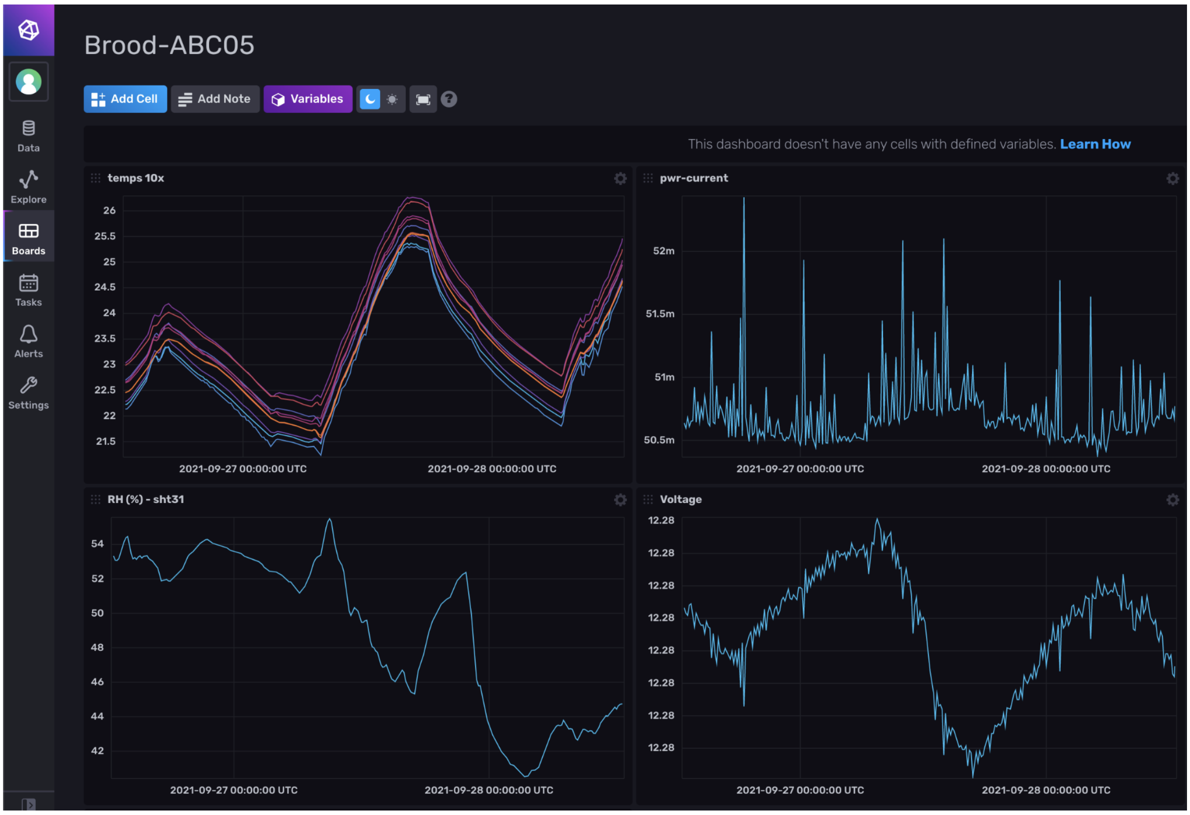


Figure 3: Screenshot of the central core InfluxDB database dashboard showing four different data types from the electronic frame (temperature of 10 sensors, relative humidity, current drawn and input voltage) spanning over two days.

This database is used in several elements of the central core beyond the logging of the data; including feeding predictive models that are executed on the core, either in raw, aggregated or processed form (some of these models are described in D5.2); and also to generate alerts if any module is detected as operating out of bounds. As part of the link between data warehouse (WP3) and external interfaces (WP1) we have developed an alert mechanism that can use arbitrary and complex queries on the database, beyond the simplistic mechanisms provided by InfluxDB itself. When an alert is generated, a Hiveopolis cloud service receives this and forwards the alert to an appropriate notification service (Slack or Discord endpoints, for example).

Physical elements in environmental sensing

The first segment of the video (assembling a Hiveopolis unit) illustrated several parts of the environmental monitoring system. This includes: (a) modules developed for measuring the traffic of bees within the hive, see Fig 4 Right. The integration of these modules is shown here, and video D3.2B shows details of the biological validation of this approach to sensing, as well as other aspects of the bee traffic management system. (b) Wireless nodes that sense temperature, humidity and CO_2, and due to their small size can be located in multiple parts of the hive, e.g. to identify gradients in these measurements. See Fig 4 Left. (c) Sensing the local environment and weather. Here, we use a commercial weather station (manufactured by Fine Offset), selected because of the small dimension of the base unit and ability to capture the data transmitted in Ecowitt formats, extending open-source libraries to inject the data into the core's on-hive database.

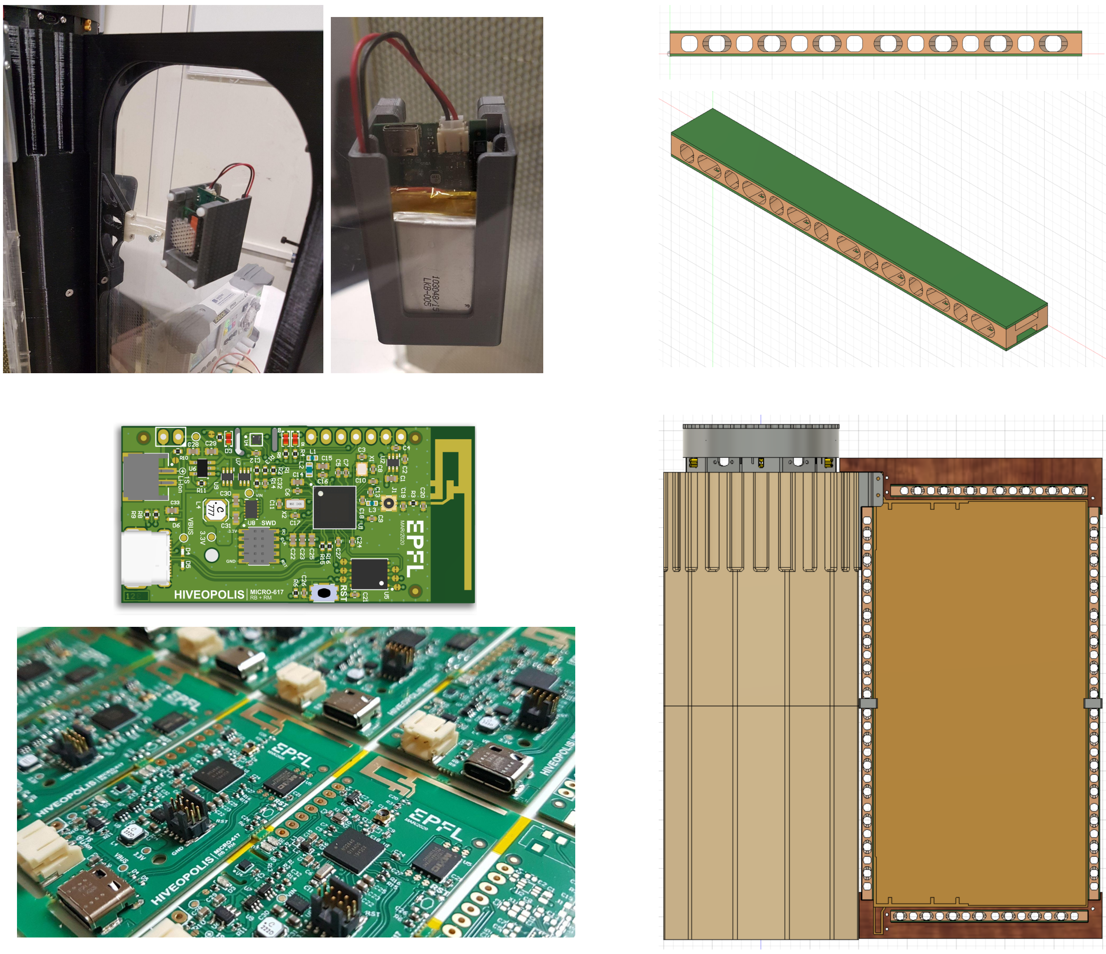


Figure 4. Left: environmental sensor, measuring humidity, CO2, and temperature levels. Each low power node operates from a battery, and transmits readings to the central core via bluetooth low energy. A node is shown here installed in a tech wedge, with laser-cut openings to allow for gas exchange/measurement whilst also preventing bees to enter. Right: a recent iteration of the traffic observation module, using photoelectric sensors and infra-red emitters to sense when bees pass through each channel. The lower image shows how six such modules are assembled to surround one frame and thus measure bees passing from one side to the other. Video D3.2B shows further detail on the bee traffic management system.

The external sensing provides measurements of temperature, humidity, wind speed, wind direction, rainfall, UV and light levels, which are relevant for various bee colony activities including foraging opportunities.

A final element in the environmental sensing makes use of information at a wider scale. It does not feature in this video since there are no physical elements in the core or within the hive, but rather, we use the augmented maps developed within WP1 as a service to provide information such as weather forecasts and foraging maps. These information sources are available on demand, using a request/response communication pattern: the central core formulates its query on the map channel, with the hive name and a unique request ID, as well as the datatype request and coordinates. The responses are accessible only to those with rights to this specific hive name, and the request ID allows for matching of the information and type. The coordinates are supplied from the central core's GNSS system. Further details of this system and other services will be reported in D3.3 on the data warehouse and D1.2 on the external interfaces later in the project.

Chapter 2: Demonstrator video D3.2B - Prototypes and progress of the repulsion and confinement system and the 'bee traffic control system'

The ultimate goal of this system is to protect both bees and beekeepers by reducing the need for them to interact, for example during honey harvesting. The aim of this system is to repel bees from certain sections of the hive by means of stimuli such as air flow. Besides aiding any automated harvesting systems (WP6), other potential applications include simplifying inspections such as of the brood nest and larval development (WP5). The video D3.2B shows three components that are needed to enable a functioning bee traffic system in the hive:

a) detection of bee movements and bee location;
b) local repulsion of bees;
c) local confinement of bees.

Detection of bee movements and bee location

To steer the bees, for example, away from honey storage areas, the position and activity of the bees must be monitored. This information is needed for controlling the activity timing of the local repulsion and confinement components.
We have tested various systems for this purpose. Two arrays of light barriers connected in series turned out to be a possible candidate for successful detection of moving honey bees. The advantage of this system is that it can successfully detect the direction of movement. Using the information of which photoelectric element detects first is a reliable indicator for whether the movement is either from left to right or from right to left. This technology is particularly suitable for use in certain constricted areas of the hive, such as between combs. We also tested acoustic sensors, which are suitable for detecting the activity of bees in places that are larger and cannot easily be occupied by other sensors. This method of activity measurement mainly detects substrate vibrations.

Local repulsion of bees

To give the bees an incentive to leave a certain area, air flow appears to be particularly viable. The bees are not simply blown off the honeycomb by compressed air, but leave these areas by walking away. Various experiments have shown that too much air pressure is actually a hindrance to this task, as the bees may then cling to the comb to avoid being blown away. After first successful trials with a single airflow outlet, we also built an array of airflow outlets, which allows a larger area of the honeycomb to be cleared of bees. After the stimulus is inactive, the bees return relatively quickly to this area. In order for a beekeeper to remove the honeycomb from the hive with as little contact with bees as possible, it requires local confinement of honeybees to prevent them from flocking back to the honeycomb.

Local confinement of bees

In order to avoid hurting the animals with rigid moving components, we tested a soft-robotics approach to close off certain areas inside the hive. A silicone layer can be filled with air and by expanding block passages. We were able to show that bees can be prevented from passing through a corridor by this method. The materials tested unfortunately did not give high reliability and the devices ruptured under a relatively low number of expansions (not shown). Another method, which does not use moving parts at all, makes use of funnel-shaped constrictions through which the animals pass in one direction but not the other. In a temperature gradient where animals are trying to reach their preferred temperature (about 36 °C), animals are able to cross such a formed barrier relatively easily in one direction, but not in the other direction.

Appendix: Links to videos

Compressed videos are uploaded to the EC portal. Higher resolution videos can be found online at the following locations:

Video Demonstrator D3.2A: https://youtu.be/49zWg9CqWcw

Video Demonstrator D3.2B: https://youtu.be/ocI9mlHcsEg