FUTURISTIC BEEHIVES FOR A SMART METROPOLIS

Deliverable D2.3

Design prototype of an innovative beehive

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Introduction

Purpose and scope of the document

This document supports the demonstrato video deliverable which presents the HIVEOPOLIS hive design and its adaptive functionality provided primarily by its physical structure. The main aim of the proposed hive design with an innovative modularity – what we call “Star–Topology” or “Star-T” – is the embodiment of the computational central core (D3.2A), and the distribution of technologies which are developed in other work packages. This entails the integration of sub components which make the HIVEOPOLIS biohybrid complete. Thus, we predict that there might be subtle design changes during the following integration period (T2.5). Here we demonstrate the structurally and biologically verified prototype which is ready for the technology integration.

Overview of the document

We provide a detailed description of the design prototype of the HIVEOPOLIS hive (Task 2.2 Create and manufacture an innovative beehive design), presented in a demonstrator video linked to this document. In chapter 1, we briefly describe the background and concept of our HIVEOPOLIS design. In chapter 2, we describe the latest hive design iteration and our efforts to model the mechanical structures and the complex forms, manufacture custom modules and novel materials and test the full scale structures on field with honeybee colonies.

Acronyms and Abbreviations

Acronyms and Abbreviations	Definition
DOW	Description of Work

1. Design Background and Concept

In the wild honeybees (*Apis mellifera*) typically inhabit hollow tree trunks in which they build their wax comb structures. By studying these structures, practising beekeepers created the artificial honeybee nest that we call the beehive. Performance improvements of beekeeping in conventional box modules stem from the beekeepers' demands to actively affect colony performance. The beehive modularity allows by varying the size of the volume of the beehive, the number of cells available for brood and nectar storage, as well as resource availability by rearranging the hive, providing food when environmental sources are scarce or taking nectar away from the colony to encourage the bees to collect more. We began the design of the novel topology of the bio-hybrid hive with a spatial concept inspired by nature. Our main design challenge here is to provide a modular hive structure that supports a high spatial connectivity between areas assigned for varied functions (brood, dance, honey) and between the colony life and our technological elements, especially a powerful computational station. Therefore, we looked at the natural systems in which skeletal structures connect living bodies spatially as information and transport networks and support them mechanically, usually connected to a source of nutrition, support or seed – such as corals, an apple or the animal bodies with radial symmetry. Despite the fact that we have multiple objectives and competing design criteria (naturally dense and connected superorganism and robotic elements coexisting), our goal is to converge on inner nest forms that resemble natural tree cavities in terms of proportions (tall and narrow) and volumetric measure (25L to 40L).

The merge between the honeybee superorganism and beekeeping practices developed over the years. HIVEOPOLIS pursues a design goal to support a seamless integration of novel technologies into the honeybee superorganism’s nest and therefore to offer numerous benefits to practising or hobbyist beekeepers, researchers and natural science educators. In the HIVEOPOLIS hive topology, which we call the “Star-T”, we use a radial grid in order to distribute the bee inhabitation modules around a central axis which serves both as the structural and computational core of the hive. This type of spatial configuration can be seen in both natural and man-made architectures in which a seed, a control tower, a power supply must be able to easily (shorter paths) reach all areas of the structure. By placing a core structure with computational elements right in the middle of a superorganism, which likes to live in well connected clusters, we aim to answer questions around robot - animal interaction scenarios, this time applied sustainably and in field conditions as opposed to laboratory experiments. Apart from making the established beekeeping methods easier to apply by automating some and allowing others to be triggered remotely, without the need to open the beehive, the integration of technological components enables entirely new ways of affecting colony dynamics. The design of the beehive structure itself supports the foraging guidance such as the inhibition of bees foraging from certain locations (areas with pesticide use) or directing them towards certain patches of vegetation to promote pollination.

During our design processes, we conducted several experiments to study how bees accept the novel topology, both in their active season and during overwintering. We also studied the application of beekeeping practices to this biohybrid beehive. This document primarily serves to support the demonstrator video, in which we present the most recent iteration of the HIVEOPOLIS design (Star-T) as well as a novel biodesign methodology that could be used to produce parts of the Star-T hive in order to biotechnologically augment the honeybee superorganism's man-made nest.

2. Demonstrator video D2.3 - HIVEOPOLIS Hive Design

The main goal of this design is to be able to monitor and interact with the honeybee superorganism from within, reducing the need for the stake-holders to regularly open the hive. This is provided by designated spaces – tech modules – for monitoring and actuating hardware facing each side of the individual comb modules and their modularity which allows the reconfiguration of these modules around the central core. The modular approach helps to accommodate for different configurations based on factors like local climate, season, colony size, the goals of the beekeeper and others. Beside the tech modules, in the case of artificial brood comb (WP5), the technologies are embodied within the comb foundation which structurally and computationally depends on the central core of the hive. We describe the hive design by referring to the design brief we have proposed in the DOW:

a) A bio-inspired structure built using bio-based materials.
b) Allows the optimum performance of the honeybee colony
    i) Without posing challenges for the development of the colony.
c) Modularity
    i) Digital design and fabrication for open-source ready design.
    ii) Kit of parts assembly
    iii) Easy access to the individual modules using the “bee repulsion” functionality (WP3, D3.2)
    iv) Adaptivity to the seasonal changes in the colony size, to support thermoregulation and different use-cases.

2.1 Star Topology

Composition

The star topology can be subdivided into bee space and tech space. Bee space is the portion of the hive hull volume that the bees can access and occupy. It follows the strict sizing and spacing requirements of honeybees and is designed to facilitate the operations of the colony. The tech space is the portion of the hive volume that is dedicated to housing the various sensors and actuators that compose the HIVEOPOLIS closed loop technology. The technological components of the biohybrid need to be positioned in a way that allows them to function, without disturbing the normal operation of the honeybee colony.

The requirements of honeybees often compete with the integration of technology. Resolving the competing requirements of honeybees, technological components and the beekeepers is the main motivation behind the search for a novel topology as well as the main design challenge. Thus the space inside the HIVEOPOLIS unit is separated into bee space and technological space.

Bee Space

The bee space inside a HIVEOPOLIS unit can be subdivided into three main parts - the dancefloor, the brood nest and the honey storage area.

The journey of a bee entering the hive begins at the entrance - a small opening in the hull with a flat surface serving as a landing pad, that allows bees to enter and leave the hive. Later the counter that tracks colony activity will be integrated here.
The dance floor is typically located inside the hull at the entrance of the hive and is where foragers deliver the resources (nectar and pollen) they have collected and interact with other bees. This section is where the dance detection and suppression systems, as well as the dance robot bee will be integrated. Together these systems allow the control loop to monitor and influence the foraging decisions of the colony.
The brood nest is the area of the hive used by the queen to lay brood inside the cells. In traditional beekeeping the queen is typically constrained to this area during the periods of active colony development. In this way the beekeeper ensures there is no brood in the honey storage area and honey can be safely extracted without harming any brood and hindering colony development. The star topology allows for the integration of inspection technology inside the tech modules which will monitor brood development and queen activity, informing the actuators on the control loop (i.e. augmented brood frame).
The honey-storage area is where the collected nectar is stored and turned into honey. This section will host the honey harvesting system, allowing the user to safely and easily draw small amounts of honey out of the hive. The extraction system can also be used as an actuator to control stored resources and influence colony decision making.

Tech space

The intention of the tech space is to create a barrier between honeybees and electronics so that there is no risk of short circuits or damage to the technological components. **Technological modules** are parts of the hive volume that house the electronics and prevent the bees from being in contact with them, but still allowing the sensors to function. For example, technology that monitors brood development and bee activity are placed behind separators that allow data to be gathered, not allowing bees to access the electronics. The main spaces for technological components are the “tech wedges” and the central column.

One of the main requirements that guided topology design was the requirement to monitor all frames from both sides so that the biohybrid can monitor and influence factors like brood development, resource levels, queen activity and others. The need for such observation is what guided the radial topology, with each frame having tech modules on both sides that can house observation sensors.

2.2 Modularity and adaptability

Active season

During the active season the bee colony starts growing in numbers so it can produce as many foragers as possible and maximise nectar inflow when it is available. After nectar flows peak the colony starts to decline in numbers and prepares for overwintering by optimising the number of individuals to be able to maintain habitable conditions inside the hive with the resources available. Part of beekeeping practice is to vary the volume of the hive with the change in size and space needs of the colony. The HIVEOPOLIS hives allow the beekeeper to make these volume changes by varying the proportion of honey storage to brood nest space (Figure 1). The separation is achieved by the **separator module** that allows worker bees through an opening which is too small for the queen. Effectively this ensures that the brood is only located where the beekeeper wants it to be.

Depending on the climate in the region where the hive is located there are various practices employed by beekeepers to help the bees with climate control. One example is the use of open bottom beehives in warmer southern climates, which help the bees with ventilation and humidity control. These types of hives are not popular in cooler climates where the hive bottom is closed. In order to be compatible with both approaches, the star topology offers the option to open or close the bottom of the beehive depending on the region, the weather conditions in a particular year or the preferences of the beekeeper.

Honey Harvesting

The honey harvesting module allows automated harvesting of a fraction of the honey stored by the bees inside the HIVEOPOLIS unit. Automated harvesting allows for small portions of the honey to be extracted without accessing the bee space or interacting with the bees directly in any way.

Accessibility

Each section of the hive hull can be accessed individually without opening the whole bee space. Individual access is achieved by a modular feeder compartment that can be removed only partially to allow access to one module only. This approach has the benefit that it limits the loss of environmental conditions, which the bees have to restore after every beekeeper intervention. In addition with the help of the bee repulsion system and the traffic control system the space where the beekeeper has to work can be free of bees, making manipulations easier and safer.

Winter Season

The strategy of bees for overwintering poses a specific challenge to the star topology. Bees usually overwinter by clustering together so they can collectively maintain a suitable temperature in the cold winter months. This cluster typically spans several frames, which in a traditional beehive are parallel to each other. In the star topology the requirement to monitor all frames from both sides requires us to separate the frames from one another so that an observation sensor can be placed between them. This prevents the colony from forming a proper cluster and reduces their chances of successful overwintering. In order to resolve this conflict we designed a special **overwintering module** (Figure 1 right) which provides 4 parallel frames where the honeybees can form a proper cluster. In addition it closes off the overwintering space, facilitating temperature regulation. The overwintering module takes the place of two regular modules and is typically installed as part of the beekeeping procedure that prepares the colony for overwintering and is removed in spring when the colony is prepared for expansion.

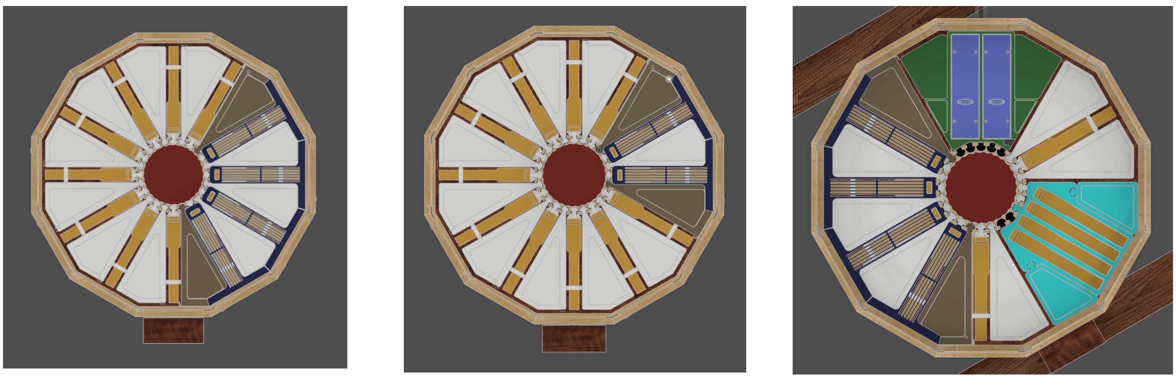

Figure 1. Examples of seasonal configurations. Left: Large brood area configuration without honey harvester. Middle: Smaller brood area configuration without honey harvester (These two hives are not equipped with electronics or a honey harvester, suitable for natural beekeeping). Right: A winter configuration with a honey harvester module. This hive is fully equipped with core electronics and the honey harvester module can be utilised as a back-up heating mechanism during the cold winters.

2.3 Biomaterial Design

Beehive constructions that combine the thermal insulation capabilities of mycelium materials with its bioactive medicinal characteristics have been investigated. Our primary objective is to develop a design-to-fabrication method which can be used to create a mycelium beehive that is alive and self-healing, with the potential to improve the health of bee colonies. As the demonstration of our fungal biofabrication method, we designed and built mycelial hives using digital technologies (procedural geometrical modelling and 3D printing) to keep the macroscale structure stable while allowing the fungal organism to continue its metabolism during the beehive's operating stage. Our fungal biofabrication method can be deployed to produce the parts of the Star Topology hives such as the roof element which can be grown to become water-proof and lightweight, or the whole hull which can be grown to be thermally insulative and steady.

2.4 Conclusion

The Star-T hive topology is an innovative beehive concept that merges the benefits of natural honeybee nests – in terms of both geometrical and material aspects – and artificial beehives used in beekeeping practice, introducing a layer of technological tools that together form a novel bio-hybrid superorganism with improved performance. The adaptive modular structure subtly houses the colony and the technological layer allowing safe and beneficial coexistence of the two inside the HIVEOPOLIS beehive. The topology is flexible and modular, allowing the user to adjust based on the local climate, the seasons and the changing needs of the honeybee colony. In addition it lets the beekeeper easily and safely access parts of the technological components with minimal disturbance to the bees. Meanwhile, advanced digital modelling techniques are used to create organics forms, construction details, fabrication files and scaffolds for biologically grown materials such as fungal mycelium, allowing the HIVEOPOLIS community to join open-source design and fabrication communities. The next big step is the integration of the various sensors and actuators within the Star-T hive.

2.5 Demonstrator video

The video linked below demonstrates the results of the design process.

https://www.youtube.com/watch?v=Q-v8btxHAic