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NEST – A platform for the acceleration of innovation in buildings

NEST – una plataforma para acelerar la innovación en edificios

P. Richner (*), Ph. Heer (*), R. Largo (*), E. Marchesi (*), M. Zimmermann (*)

ABSTRACT

The speed and quality of innovation in the construction sector has to be substantially increased in order to meet the pressing challenges associated with the building stock. For this purpose, the NEST project was started in Switzerland. NEST is a flexible and open research and technology transfer platform for partners from academia and industry where new solutions can be implemented and validated in a real life environment. NEST consists of a backbone, the static part, and research units which serve as office or living space where people live and work. Each unit is addressing specific research topics such as timber construction or digital fabrication and bears numerous innovation objects which are subject to continuous development and evaluation. NEST is a vertical neighbourhood of units, which are connected to a water hub and an energy hub. Once the research questions in a unit are answered and new products have been developed, the unit is deconstructed and replaced by a new unit addressing new topics.

Keywords: open innovation, living lab, energy hub, water hub.

RESUMEN

La calidad en la innovación dentro del sector de la construcción debe ser rápidamente adaptada para cumplir con los inmediatos desafíos relacionados con la mejora de las edificaciones actuales. NEST es una plataforma de investigación y transferencia tecnológica flexible y abierta a universidades e industrias donde nuevas soluciones pueden ser implementadas y validadas en un entorno real. NEST consiste en una estructura fija con una serie módulos individuales que son utilizados como oficinas o apartamentos donde poder vivir y trabajar. Además, cada uno de estos módulos actúa a modo de laboratorio donde se investigan diferentes aspectos como el uso de madera como material de construcción o la fabricación digital y donde, continuamente, se lleva a cabo el desarrollo de materiales innovadores, así como su evaluación. NEST es un edificio modular cuyas unidades están individualmente conectadas por medio de redes comunes de suministro de energía y gestión y tratamiento de aguas. Cuando finalizan los estudios asociados a un módulo y los nuevos productos han sido optimizados, éste es desinstalado y remplazado por una nueva unidad de cara a abordar nuevos retos e investigaciones.

Palabras clave: *innovación abierta, laboratorio vivo, cubo de la energía, cubo del agua.*

(*) EMPA -Swiss Federal Laboratories for Materials Science and Technology (Suiza)
Persona de contacto/*Corresponding author*: peter.richner@empa.ch (P. Richner)
ORCID: http://orcid.org/0000-0002-5664-613X (P. Richner); http://orcid.org/0000-0003-2999-5753 (Ph. Heer); http://orcid.org/0000-0002-1284-2470 (R. Largo); http://orcid.org/0000-0003-0266-8525 (E. Marchesi); http://orcid.org/0000-0003-0962-4234 (M. Zimmermann)

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1. INTRODUCTION

A sustainable built environment is a precondition for sustainable development of a society. Buildings which offer comfortable and affordable housing and functional space for work are as important as an efficient infrastructure which provides reliable transport of people, goods, water, energy and information. Depending on the state of development of a society, the challenges regarding the built environment are very different. In many developing countries the focus lies on the establishment of a basic infrastructure and housing for everybody while in the developed world the focus is on the transformation of the existing built environment towards a much more sustainable one.

The key elements driving this transformation process in developed countries such as Switzerland are climate change, energy policy and substantial demographic changes of the society in the coming decades. As a midterm goal, Switzerland is committed to reduce the overall CO2 emissions during the period 2013-2020 by 15.8 % compared to 1990. Within the new energy policy which has been formulated in the aftermath of Fukushima the nuclear phase-out, large improvements in energy efficiency and increased use of renewable energy are planned. Presently, the Swiss building stock is responsible for roughly 50 % of the national CO2 emissions and for 40 % of the end energy demand (1, 2). The building sector is therefore required to reduce its environmental footprint dramatically over the coming decades.

This is not only a challenge for the construction sector but also a unique opportunity. Deep renovation of existing buildings, replacement of old and unsustainable buildings by new ones and the increased use of renewable energy in buildings will fuel the development of the sector over the coming decades. To make all of this happen, an acceleration of the innovation speed is mandatory. Switzerland is well positioned to follow this road since the Swiss research community ranks amongst the best worldwide in the construction area. However, the transfer of new ideas and concepts from the research world into practice takes far too long. The main reason is the risk aversion of planners, contractors and clients. There are two main reasons for this: high investment costs and lifespans of 30 years and more. As long as new solutions have only been proven at the lab scale, the direct implementation in real scale construction projects is very unlikely. Traditionally, mainly pilot and demonstration projects have been used to close this gap. In such projects extra money is set aside for the upscaling and the additional planning and implementation efforts needed. Furthermore, monitoring campaigns are included in order to validate the new solutions during operation. Typical cases in recent years are the office building Forum Chriesbach in Duebendorf (3) or the new Monte Rosa mountain hut (4). In both cases, the state of the art in terms of energy use and water management was redefined for the respective use case and many of the approaches used in these buildings were adapted for other cases in the meantime. However, in both cases it was clear from the beginning that the buildings had to meet all user needs after completion and therefore concepts and technologies applied needed a high technology readiness level (TRL) of 7 and higher according to the definition of EARTO (5). In other words, only relatively mature ideas could be realized.

The concept of living labs has emerged as one way to allow the upscaling of solutions at lower TRL under close to real life conditions. Numerous projects have been implemented in the last years, each with specific characteristics and thereby contributing to the definition of the living lab concept in the building sector (6). The NEST (Next Evolution in Sustainable Building Technology) was developed under the leadership of Empa and Eawag and is described in detail in this article.

2. THE NEST CONCEPT

A first complete experimental unit named SELF was developed by 2010 (7, 8) based on the experience that in user dominated buildings such as Forum Chriesbach or the New Monte Rosa hut it was impossible to experiment with solutions at a low TRL. SELF is an autonomous living and working unit for two persons (Figure 1). The unit is not connected to any electrical or water infrastructure. Instead, all energy is harvested, converted and stored locally. Sun light is harvested by high efficiency PV panels and the electricity is stored in batteries. Excess electricity is converted to hydrogen which can either be used in a fuel cell to produce heat and electricity or for cooking. Cooking is done via a silicon carbide based catalytic hydrogen diffusion burner. It improves the energy management especially during the winter season when the PV panels do not supply enough electricity. Rain water is collected on the roof and filtered and can be subsequently used as drinking water. Waste water from the sink, shower and dish water is treated appropriately and can be reused as technical water for all purposes except as for drinking. Besides the numerous scientific results that were generated in the SELF project, the fact that SELF is a mobile platform which can be brought to trade fairs or other public events proved to be of special value. SELF serves as a stimulus for discussions with all stakeholders including researchers, planners, suppliers of building technology and most important with potential users.

The success of SELF triggered the development of NEST (9), a large scale research and technology transfer platform. NEST is based on the following pillars:

- Private public partnership (PPP)
- Open platform for partners from academia and industry, both national and international
- R&D dominated, but including real users
- High flexibility

These four pillars were defined in order to support the innovation process in an ideal manner. From the very beginning, all relevant stakeholders of the innovation process are included thanks to the PPP approach: academia, industry and public authorities. They all contribute to the richness of the NEST ecosystem and at the same time ensure a stable financial basis for the platform. NEST is a complex but highly flexible undertaking, which can only be fully used if it is operated as an open platform. All players from the sectors are welcome to propose topics and ideas which are then evaluated within the NEST innovation process as described later. NEST is designed as a living lab which means people are living and working in the experimental parts of NEST. This is needed in order to develop new solutions under conditions as close to reality as possible. However, the researchers and engineers are in full control of the operation and the users become part of their experiments. Two control systems have been implemented: an engineered system and research system. Higher risks can be taken under such conditions compared to user dominated settings because there is no formal

Figure 1. The autonomous living and working unit SELF.

obligation to reach a specific service level at any time. In case a research solution fails, the researchers can switch to the standard control system and analyze the reason for failure, develop an improved version and implement it again. Finally, NEST is designed to offer maximum flexibility so that complete office or living areas can be constructed, operated, dismantled and replaced by new units with a different thematic focus over time.

NEST is a three-story building consisting of a backbone, the static part of the building, and research units which form the dynamic part (Figure 2).

The backbone is made of a core with an atrium surrounded by meeting rooms, technical rooms and free-standing platforms on the outside, which serve for the construction of the units (Figure 3).

The three platforms have a total area of approximately 2'500 m2 and can accommodate one story units on the first and second floor and two or even three story units on the third floor. The platforms on the first and second floor can carry a maximum load of 10 kN/m2 and 12 kN/m2 on the third floor. Seven access doors and technical interfaces are available for research units on each floor. Other than that, there are no limitations for the construction sites of the units. This offers considerable variability for the units in terms of orientation and floor plan.

NEST can be seen as a vertical neigbourhood. As such it provides an energy and water infrastructure for the units. Each unit is independent and is a small building in itself. The units are connected to the infrastructure via the technical interfaces (see Figure 3). A multi-energy grid and the ehub form a model for future distributed energy systems (10, 11, 12). The multi-energy grid consists of three thermal grids at different temperature levels, a gas grid and an electrical grid. Other grids can be added in the future. The function of the ehub is to store, transform and distribute energy with the main objective to maximize the use of locally harvested renewable energy and to minimize peak demands. The water hub is located in the basement and consists of various facilities for processing different types of wastewater streams that are already separated at unit-level. The backbone is equipped with five independent wastewater piping systems to which the units have access via the technical interfaces.

3. NEST INNOVATION PROCESS

The units are the core elements of NEST. The innovation process is structured along the development and operation of the units (Figure 4) and includes six phases which are characterized by requirements and deliverables. A unit is developed, built and operated by a consortia consisting of partners from academia and industry. A substantial part of the cost is covered by the consortia by in kind contributions. Furthermore, a NEST fund was created where companies or public bodies

Figure 2. Outside view of the NEST building with the Backbone and two units: Meet2Create on the first floor and Vision Wood on the second floor.

interested in innovation in construction in general can engage themselves financially. These means are used to support the operation of NEST but also the development and operation of units. Finally, application oriented funding organizations such as the Commission for Technology and Innovation in Switzerland or Horizon 2020 are additional sources for funding. Based on the experience so far it can be assumed that overall the costs for units are equally divided by the public and the private sector.

The NEST team is steering the innovation process. At the end of each phase the corresponding deliverables are checked by the NEST team and if reached, the next phase is started.

During the ideation phase the scientific and economic potential of the project are assessed. The main deliverables include:

- Description of the research topics and innovation objects. Innovation objects are new technologies, systems or processes which will be developed and validated within the unit.
- Qualitative analysis in terms of sustainability (decarbonization of the energy mix, ecological aspects, social impact, market potential of the new solutions).

The main goals of the concept phase are the definition of the research roadmap, the technical specification of the innovation objects and a formal agreement with the main partners from academia and from industry for the development and operation of the unit. A first architectural draft for the unit has to be developed which shows how the different innovation objects are incorporated and also what type of use for the unit is planned (office, living, mixed, other). A concept for the integration in the energy and water hub has to be provided as well. As a result of this phase, a first cost estimate for the construction of the unit including a funding scheme is also required.

The planning phase is very similar to the one of a conventional construction project and follows the process described in the Swiss standard SIA 112 “Modell Bauplanung” (13) with minor deviations. The implementation of building information modelling (BIM) is highly recommended during this phase. The planning of the units is more complex than in ordinary projects and substantial changes have to be expected even during the operation phase. Therefore, a comprehensive IT-based planning and documentation tool is essential. At the end of the planning phase the construction permit should be granted by the local authorities and a cost estimation with an uncertainty range of 10 % has to be provided for the construction of the unit.

The construction phase is also structured according to the Swiss standard SIA 112 and ends with the completion of the unit and the delivery of the complete documentation.

During the operation phase the performance of the various innovation objects is analyzed in a scientific manner. Depending on the results, further developments might be needed in order to reach the expected performance level. Therefore, units have to be designed in such a way that critical parts can be continuously further developed. This might imply the replacement of complete parts of the unit such as parts of the façade, HVAC systems or illumination systems depending on the topic of the research. The validation is supported by an extensive sensor network which gives access to information regarding time resolved energy demand, water use, occupancy and all other specific information related to the different innovation objects.

The units are occupied by users in order to create a realistic use scenario. Depending on the conducted research, the users will give specific feedback about the performance of the new technologies. This feedback is collected via interviews, questionnaires or by observing the interaction of the users with the innovation objects. In the office unit Meet2Create this approach has already lead to the replacement of a first generation of office furniture by a second one. It was based on the observation that some of the objects were not used at

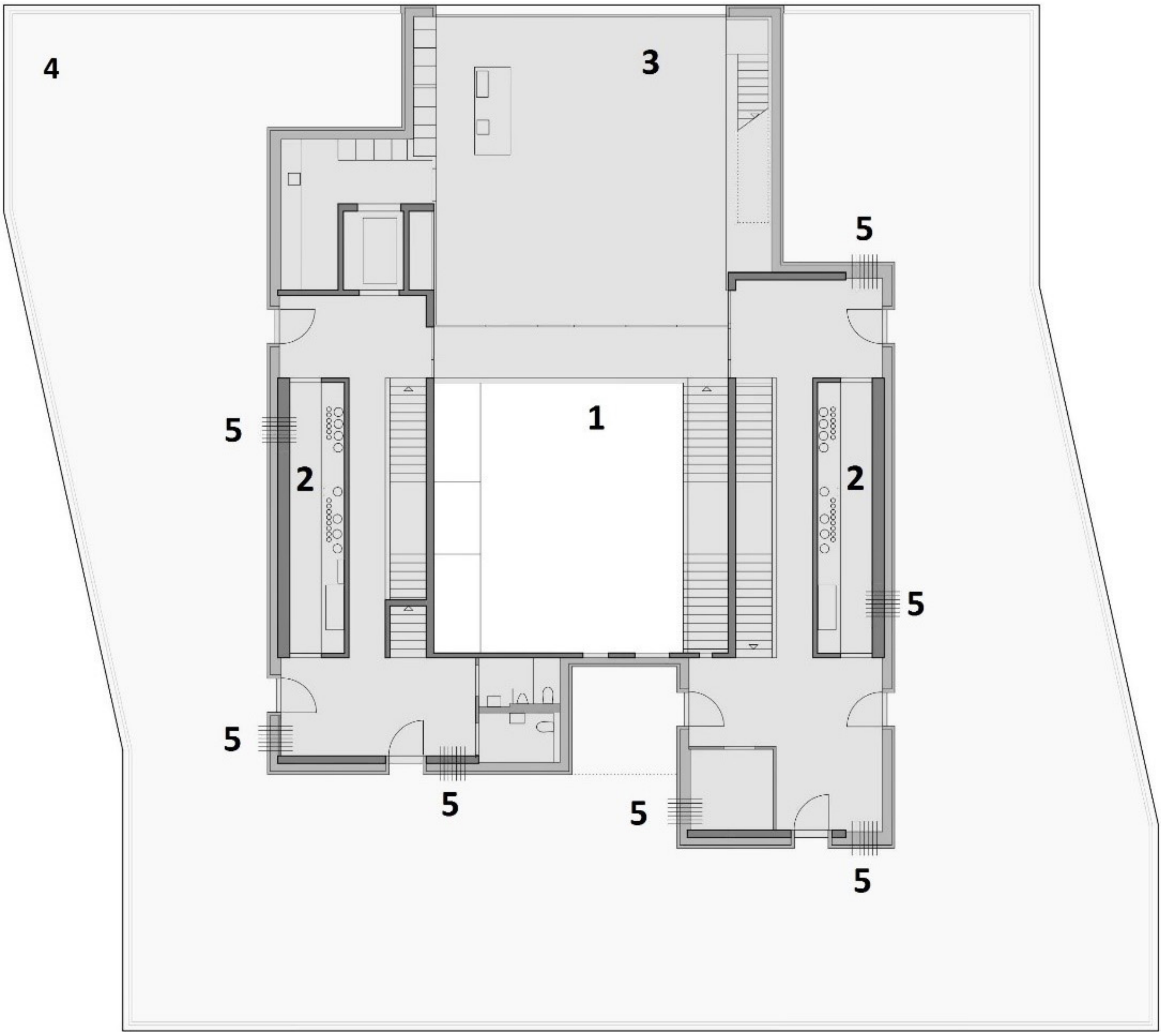

Figure 3. Ground plan of the second floor with the atrium (1), the zones for media distribution (2), a large meeting room (3), the platform for the units (4) and the technical interfaces (5).

all and interviews with the users revealed the reasons for this behavior. Furthermore, NEST is visited by approximately 1'000 people per month. During the guided tours the reactions of the visitors towards the different innovation objects is registered by the guides and transferred to the responsible research partners. The interest and the qualitative judgement of the innovation objects by the visitors gives indications about the market potential and also about strengths and weaknesses of the proposed solutions. More quantitative measurements of user satisfaction is planned for upcoming units especially related to the increased use of daylight.

Once an innovation object has successfully reached a TRL of 7 or higher, market introduction by the industrial partner can be envisaged. NEST allows fast learning cycles in close collaboration between researchers and industry and consequently TRL 7 should be reached faster and with higher probability.

Finally, a unit will reach end of life after several years when all the research questions formulated have been answered and the deconstruction phase can start. The unit will be dismantled and gives room for a new unit which is going to address new topics. The deconstruction of the unit will be a project by itself since it offers the opportunity to finalize a complete life cycle analysis and it can also be used to validate the potential of the specific design to reuse materials or even components.

4. CURRENT TOPICS ADDRESSED IN NEST

When NEST was inaugurated in May 2016, two units plus the energy and the water hub were operational. Five more units are currently in the concept, planning or construction phase and will be completed within the next 6 to 24 months (Table 1). By that time, around two thirds of the available space will be occupied.

Energy and water are common topics for all units. Each unit acts as a single, independent building which is connected to the NEST ehub via multi-energy grids. The energy performance requirements for the different units depend on their location in NEST. Units at the top platform have to focus on harvesting renewable energy and are required to have a 50 %

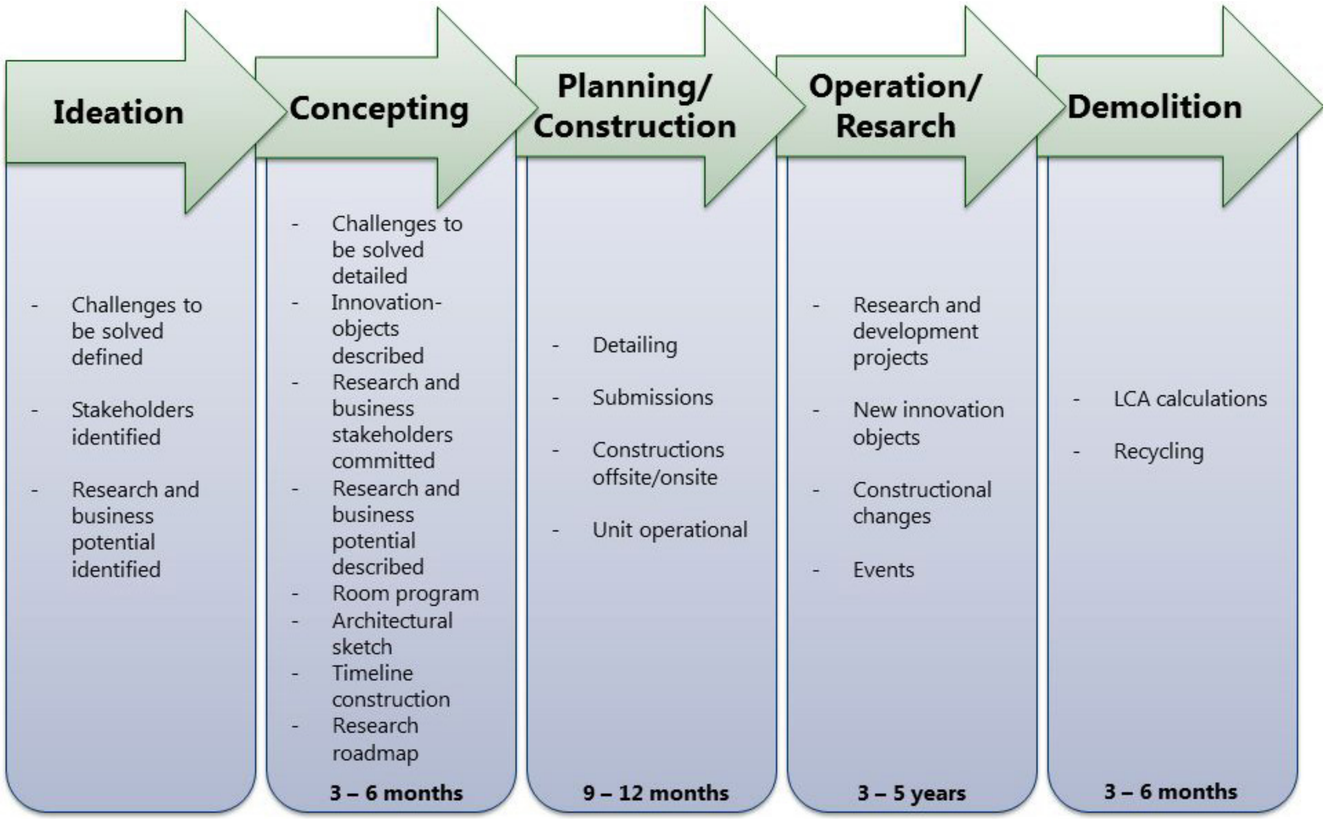

Figure 4. NEST innovation process.

surplus in their yearly energy balance. The excess energy helps to cover the energy demand of the other units on the floors below, especially those with a north-east orientation. The energy storage and conversion systems of the ehub assure that all energy harvested by the NEST units can actually be used within NEST despite the mismatch between renewable energy supply and energy demand.

The thermal ehub consists of a low, medium and high temperature grid. Based on their energy concept the units can decide to which grid they would like to connect. They can draw energy from the grid and supply excess energy back to the grid. The energy flows are monitored in order to calculate the energetic performance of each unit. The low temperature grid can accommodate a rather broad temperature range with 18°C/28°C in summer and 2°C/8°C in winter. The medium temperature grid runs at 35°C/25°C and is fueled by a heat pump that uses an ice storage and/or ground heat as a source. The high temperature grid at 60°C/40°C is connected to a high temperature heat pump and a fuel cell. The high temperature grid is needed for the local production of domestic hot water. The electric side of the ehub consists of a microgrid, with batteries (96 kWh, 180 kW) and supercaps (1 kWh, 70 kW). Following proven concepts, the supercaps serve as supply and sink for electrical power peaks, thus load-leveling the batteries and protecting them from damage. Under normal operation the state of charge of the batteries is kept at 70 % and at 50 % for the super caps. This gives enough capacity for the ehub to accept electrical energy from the units or to provide them with electricity at any time. Additionally, the access to controllable loads allows for the research on active grid management in a grid connected mode, as well as for island operation.

The design of the ehub is such that additional hardware and software components can be added if needed. For each component a LabView interface was developed for easy access by researchers. Different components can be chosen in whatever configuration and parametrization for running ehub experiments. In combination with the vast collection of measured data and simulation tools, this allows new insights on the optimal layout and configuration of decentralized energy systems. Several projects with energy providers have already started.

The water hub operated by Eawag explores new ways of water management at the level of single buildings and districts (14). The setup allows the collection of up to five different qualities of waste water from each unit: less concentrated greywater from washing basins, showers etc., heavy greywater from kitchens, urine, blackwater and one to be defined in the future. The motivation for this approach is the fact that central waste water treatment plants have to deal with blended diverse types of wastewaters which makes the recovery of valuable substances and the recycling of water difficult. This can easily be demonstrated for urine which contains the majority of nutrients such as phosphorus or nitrogen but contributes less than 1 % to the total volume. Separate process lines for the different waste water streams are currently under development. The ultimate goals are to recover nutrients, reuse greywater and use waste water as an energy source. Besides the technical challenges the acceptance by users is an important task. Therefore, new types of urine-diverting toilets are developed in collaboration with industry with the goal not to cause any odor nuisance.

The two units currently in operation are Meet2Create and Vision Wood. Meet2Create is an office unit serving as a labo-

Table 1. Overview Units.

Unit	Topic	Type of Use	Main Academic Partners*	Date of Completion
Ehub	Decentralized multi-energy grids and ehubs	Infrastructure	Empa	Q 2 2016
Water Hub	Efficient use of water and wastewater	Infrastructure	Eawag	Q 2 2016
Vision Wood	Timber base innovations in construction	Living	Empa, ETH Zurich	Q 2 2016
Meet2Create	Laboratory for collaboration and work processes	Office	Hochschule Lucerne	Q 2 2016
Solar Fitness & Wellness	Energy efficient wellness technology	Leisure	Empa, Hochschule Lucerne, Fachhochschule Nordwestschweiz, Interstaatliche Hochschule für Technik	Q 2 2017
SolAce	Perception based human control and multifunctional solar façades	Mixed living and office	EPF Lausanne	Q 4 2017
Urban Mining	Closing the urban material cycle	Living	ETH Zurich, University of Stuttgart	Q 4 2017
Digital Fabrication	Combining digital technologies with the physical construction process	Living	NCCER Digital Fabrication	Q 2 2018
HiLo	Lightweight construction and adaptive solar façades	Living	ETH Zurich	Q 2 2018

* A total of more than 60 industrial partners are involved in the units.

ratory for the interplay between users, space and technology. In order to meet the demands of knowledge workers, different zones have been developed. They include space for workshops of smaller or larger groups or rooms for concentrated individual work. Tailor made furniture for these different settings play an important role as they have a large potential for fostering specific tasks. In parallel, new approaches for the provision of an optimal climate control are developed. In this respect, it is essential to ensure that HVAC systems are only activated if the respective space is actually occupied by users.

Vision Wood is a living unit for three to four persons. The main objective is to explore ways to increase the use of timber based materials in buildings since wood is one of the few renewable materials available in construction. Several innovation objects in Vision Wood are addressing the interaction of wood with water and moisture. This includes new surface treatments for wooden façade elements which will not alter their appearance upon weathering. In wet areas such as bathrooms, hydrophobized veneers are applied and furniture made out of a new bamboo composite with excellent mechanical and weathering properties is used on the balcony.

5. SUMMARY

NEST is setup as a research and technology transfer platform for the building sector in a conserted effort by academia, industry and the public sector. It is what has become known as a living lab with special emphasis on open innovation, technology transfer and user involvement. The backbone infrastructure offers a maximum of flexibility in terms of topics to be addressed and layout of the single units. An important aspect of the NEST concept is the highly dynamic nature of the project. Units are built, evaluated and improved over time and finally dismantled and replaced by new units. Although people are living and working in these units, the units themselves are always under the full control of the research partners what guarantees that the advancement of the developments always have priority. Another important aspect is the holistic approach taken in order to cope with the manifold challenges present. NEST is addressing questions regarding construction processes, new construction materials and systems, user comfort and user interaction, energy and water management just to name a few.

Presently, more than 90 partners are involved in NEST. This can be seen as a first prove of principle of the approach taken. However, the ultimate goal is to bring new products and services to the market in order to address the challenges the building stock is facing. Chances are good that this will already happen in the near future.

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