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THE POTENTIAL OF HOOK-AND-LOOP FASTENERS IN THE BUILDING INDUSTRY – TOWARDS A CIRCULAR ECONOMY

Marisol Vidal[a]

[a]Graz University of Technology, Austria

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ABSTRACT

Sustainability of the building sector is an urgent matter, as this sector is globally responsible for about 36% of final energy consumption and about 39% of energy-related CO_2 emissions, as well as for about 40% of resource consumption. One approach to reducing these figures is to design buildings that are adaptable to different uses and therefore part of a circular economy. One key aspect of sustainability in buildings is hence the appropriate design of the interfaces, differentiating between durable and non-durable components as well as allowing the separation and reuse of the resources embedded in heterogeneous building components. The requirements for these interfaces are hence separable joints, maintenance friendliness, accessibility and standardization. Hook-and-loop fasteners are currently used in the field of textiles, tools, automotive engineering, aircraft construction, rail vehicles, trade show construction, packaging as well as in fire protection and aerospace. Although still rare in the construction industry, hook-and-loop fasteners can actually meet the requirements named above better than conventional construction joint techniques. In order to encourage a broader application of hook-and loop fasteners, this paper shows the current state of the art and the potentials of their construction-related uses by analysing research projects, patents and the first licensed building products. This includes not only applications for joints components that are easy to dismantle, but also the production of hook-and-loop components made of concrete, as well as the combination with sensor technologies and digitalisation in the context of considering our cities as valuable sources for materials and components.

KEYWORDS

Hook-and-loop; circular economy; disassembly; recyclability; fastening technology.

1. INTRODUCTION

Smart cities have become a landmark in The traditional economic model - the so-called linear economy - is based on a *take-make-consume-dispose* pattern. This model relies on a never-ending supply of cheap resources and energy and a consumer society encouraged by market strategies such as planned obsolescence and is leading to vast, negative environmental and social consequences. In contrast, the circular economy model is "an industrial system that is restorative or regenerative by intention and design" (MacArthur 2013). It proposes a model of production and consumption that involves extending the life cycle of existing materials and products by reusing, repairing, refurbishing and recycling them as long as possible, thus reducing the need for resource inputs and the creation of waste, pollution and carbon emissions to a minimum. In order to achieve a truly sustainable circular economy, we would need to change our current consumption and production practices in all fields by designing and promoting products that can be reused, repaired, remanufactured and eventually recycled.

The building industry - as one of the world's largest consumers of energy and raw materials, responsible for around 40% of CO_2 emissions and nearly a third of all waste in the EU (Adams et al. 2017) - is a key target for European policies aiming to reduce raw materials and energy consumption, the carbon footprint and waste generation (European Commission 2020). As a consequence, rethinking construction supply chains in order to help reduce and reuse waste materials and recover construction materials for further recycling and/or their direct reuse are becoming key aspects towards a successful circular economy implementation.

Material recirculation, encouraged by designing products for disassembly, can potentially prolong the service life of construction components (Eberhardt et al. 2019). While screws, nails and pin fastenings and clipped connections are currently widely used, they do have some limitations concerning their general applicability, the interdependence of building parts (Vandervaeren et al. 2022) and sometimes lead to unavoidable damage through disassembly (e.g. a manufactured board fixed in place with a nailgun). For constructions that have to be loosened and reconnected more than once, hook-and-loop

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fasteners may constitute an alternative, expanding the scope of disassembly to whose parts of the building where non-destructive dismantling and replacement is rarely if ever implemented, since clean removal means currently considerable additional work and thus higher costs.

2. HOOK-AND-LOOP CONNECTIONS

Hook-and-loop connections are a paradigmatic case of biomimetics, as it was inspired by the burdock's natural mechanism for seed dispersion (Fig.1.). A swiss engineer, George de Mestral, was granted the patent in 1955 after numerous years of development. He gave his invention the name Velcro® (from French velours "velvet" and crochet "hook"), which through metonymy has become a synonym for hook-and-loop fasteners (Velcro® 2016).

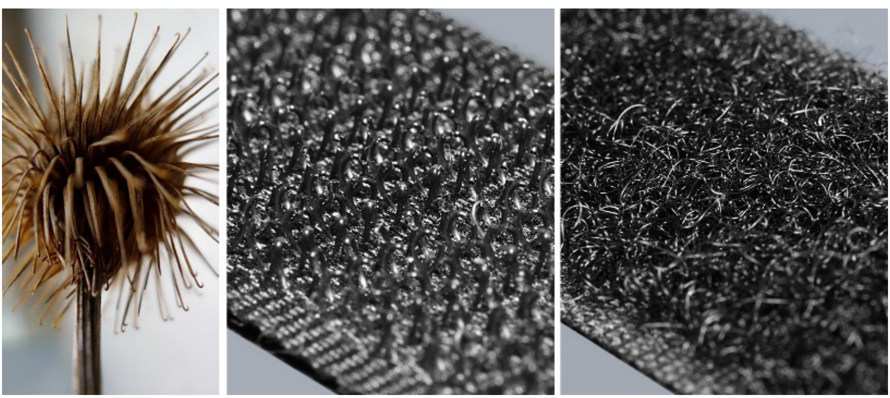


Figure 1. Burdock seeds (KlockarsClauser 2007), Textile hooks-and-loops components (Klink 2010)

A hook-and-loop fastener consists of two connection components, which connect to each other through a large number of complementary connecting elements due to their geometric and material-specific properties. Common geometric shapes of the connecting elements are hooks, mushroom heads, slings or loops. Currently used in the textiles, packaging, medicine, automotive and aerospace industry, hook-and-loop fasteners have evolved from George de Mestral's rather artisanal products to high-performance devices capable of high tensile (Gottlieb Binder 2018) and shear (Krüger 2013) strength, as well as fire (Grinfeld 2010) and acid resistance (Höhe 2009).

A worth mentioning variation is activatable and controllable hook-and-loop connections: releasable fastening systems that provide a shape change and increased bond strength when electrically activated (Momoda et al. 2002). Further patents (e.g. DE112007002135T5 and US20040074069A1) show similar switchable systems. A translation of these principles into a product prototype is the concept Active Velcro System (Brei 2003). This system is used for micro (<100 kg) and nano (<10 kg) satellites for maintenance work in space, as it enables exact positioning of the attached component. Further variations are thermoelectrically activatable hook-and-loop fasteners made of SMA wires (Afrisal 2016) and chemically and electrochemically produced activatable hook-and-loop components on a molecular scale (Ahn 2013). These examples show the high-levels of precision and performance reached in other sectors concerning hook-and-loop technology.

3. AGILITY AND CULTURE: THE BIGGER PICTURE

The building industry has always profited from the technology transfer from other sectors and we can see this happen as well in relation to hook-and-loop fasteners. However, innovation in the construction industry is a rather arduous process, where long-term, straining testing in real conditions often outweigh matters of high-tech and precision. In this sense, and in relation to the structural properties of hook-and-loop fasteners, it is important to note that the connection happens somehow randomly: every hook element can actually be attached to one or more loop elements but not all of them do. The actual number of active or completed connection points can therefore not be fully ascertained, so the possible power transmission lies within a statistical scatter range. Furthermore, many connection cycles lead to loss of strength and damage to the connection elements, so wear out tests are also necessary. The load-bearing behavior of different hook-and-loop products can also differ widely and is determined by their geometric conditions, material-specific properties of their components and the expected number of closing and opening cycles. By optimizing and coordinating these parameters it is possible to produce hook-and-loop products with high adhesive (35 N/cm²) and/or shear strength (41 N/cm²) while keeping a low peel strength (3 N/cm²). The connection itself is made by pressing together the connection partners, with an estimated contact pressure of approx. 20 N/cm² for industrially manufactured hook-and-loop fasteners. (Krüger 2013).

While still a market niche, loop-and-hook fasteners are already present in the building industry. In the following subchapters, we will analyze the most relevant commercial and research-stage hook-and-loop-based products for the building industry, setting the focus on their potential towards a circular economy. The classification of the products is based on their intended and ideal application.

3.1. Mounting systems

Mounting systems like the Metaklett (Metaklett 2010)metallic bands, the Uponor system (Uponor GmbH 2022) for underfloor heating pipes, the Vario XtraSafe (Isovere

GmbH 2022) system for the fixation of vapor-retardant membranes or the Rhepanol hfk (FDT GmbH 2022) system for roof sheeting are already available in the central European market. They all have in common the replacement of glue or metal fasteners with loop-and-hook connections, a principle that opens a wide palette of applications, as they are rather simple to implement and can be used without previous skill training. These systems target the reversible, quickly layable and/or adjustable connection of rather light components (membranes, sheets, pipes) and therefore the facilitation and cost-reduction of the montage process, but a later maintenance or disassembling of the individual components is not envisaged. Consequently, their contribution to a circular economy is almost non-existent. Firstly, because the connection between the mounting-component and the hook-and-loop components represents an obstacle to their recyclability, since it must be difficult or impossible to separate in order to fulfill its purpose. Secondly, because once correctly laid, these components often become bonded in situ through chemical bonds (e.g. screed) or plastic sealants (e.g. roof sealing) thus becoming part of a non-demountable composite layer.

3.2. Building service systems

In a similar way, some research projects are exploring the potential of hook-and-loop connections for fastening building service equipment within a building. The Klett-TGA for example, proposes a continuous loop surface along certain areas of structural elements, allowing the technical equipment to be attached through a built-in hook-mat. The target is here the flexibility for modification, maintenance and replacement of the building service equipment during the lifespan of the building (Riewe et al. 2019).
Concerning the separation and further usage of the components, the disadvantage of the connection between the component and the hook-and-loop components was addressed by using an adhesive which allows manual removal. For this purpose, the hook-and-loop mats are detached from the structural elements at one end and then removed by applying a linear load.

3.3. Interior systems

Interior systems usually target the variability of interior finishes and fixtures. The patent “Velcro system in or on a building” proposed in 2012 “a system that makes it possible to attach tiles, laminate, PVC or carpet whether plastic, stone, concrete, natural stone or any other building material via a Velcro connection to the wall, ceiling or on the floor.” (Schaumburg 2012). This patent intends to replace the conventional glue and mortar layers with hook-and-loop connections in order to facilitate the exchangeability of tiles, flooring and other cladding components. To do so, a hook or loop mat is glued to both

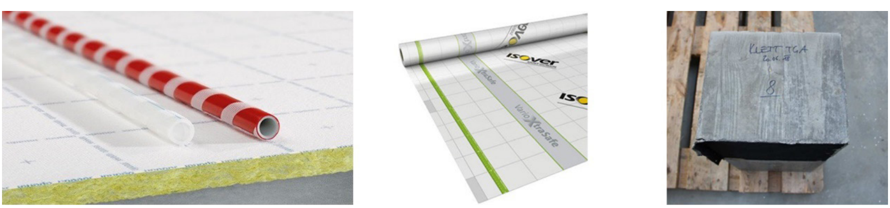


Figure 2. Uponor system (Uponor GmbH 2022), Vario XtraSafe (Isover GmbH 2022), “Klett-TGA” test specimen of making a loop surface on concrete by inserting a loop component into the formwork (Freytag et al. 2018)

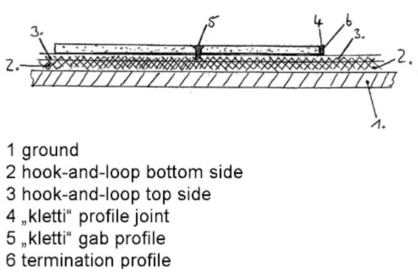
the component and the ground element it gets attached to. This means that a) an extra working step is needed and b) instead of originally one layer of glue/mortar we get two. Furthermore, all joints are also supposed to be “formed with Velcro special profiles in all colors and shapes” (Ibid.), which increases dependencies on this commercial system.

Another example of interior system is the “Gecco-Wall” by Jan Werner, consisting of partition walls that can be set up quickly and without major interventions in an existing building. The supporting structure consists of vertical supports that are braced between the ceiling and the floor. Panels can be attached to the support via built-in hook-and-loop elements. (Werner 2018). The applicability is somewhat restricted by fixed panels dimensions, probably leading to clippings at the perimeter. Also, there is no acoustic isolation other than the panels themselves so this system is probably working best for temporary settings such as open exhibitions spaces. Similar systems could be also be convenient as TGA shaft cladding or to cover inspection openings.

3.4. Façade systems

In a patent from the year 2000 (Tachauer et al. 2000), an attempt was made to replace the entire façade substructures with hook-and-loop-capable membranes, thus enabling the façade cladding elements to be easily replaced and source segregated before their disposal. The main idea is to continuously equip roofs, walls, floors and ceilings with fastening membranes consisting of hook elements arranged on both sides and using loop strips for elements such as roofing, wall or facade cladding, insulation panels or floor coverings. The hook-membranes can easily be cut to size and fixed onto the surfaces. However, the loop strips are glued and must be attached at small intervals to prevent the facade from sagging.

One of the few products in development is the façade system *StoSystain R* (Sto Ges.m.b.H 2015), a further development of the external thermal insulation composite system (ETICS/EIFS), a widespread façade system in Central Europe consisting of thermal insulation boards (usually polystyrene) tied through dowels and glued to the exterior wall surface, plus a base coat reinforced with glass fibre mesh and a finish coat giving the appearance of stucco or conventional rendered plaster. The use of a hook-and-loop connection as a means of fastening between the adjustable dowel and the plaster base plate enables adhesive-free assembly, later separation of these components according to type and their reuse or recycling. But while separating the plaster base board from the anchors is



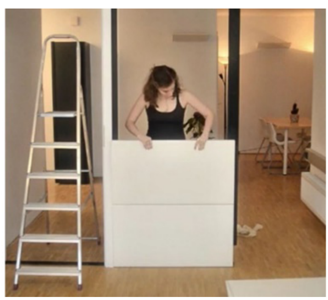
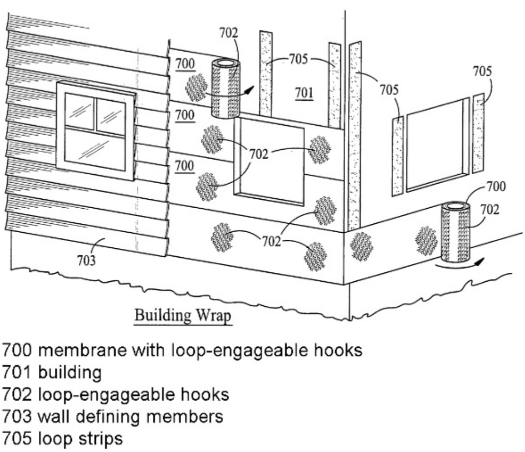


Figure 3. Velcro system in or on a building (Schaumburg 2012), Mounting the “Gecco-Wall” (Werner 2018)

easy to perform, separating the hook and loop component from the board is more difficult. This is nevertheless a significant advance compared to conventional ETICS/ EIFS systems. In addition, the dowels and the Velcro® component there could be made of the same material, thus improving their recycling.
A further, much more specific use of hook-and-loop connections in façade systems is the concept developed in the "Piezo-Klett" research project. By combining hook-and-loop fasteners with piezoelectric materials, they become energy harvesters and are able to operate active sensors thanks to the high weight loads, strains, vibrations, changes in temperature or due to air currents and wind loads occurring in buildings, without complex cabling or battery limitations (Raudaschl et al. 2022). In turn, the "Piezo-Klett" elements enable the measuring and storage of data regarding circular economy processes, helping monitoring the entire life cycle of buildings, which could lead back to more efficient recycling processes.

3.5. Concrete systems

A 2016 patent by *Betonwerk Schuster GmbH* describes a procedure in which a plastic or metal loop-equipped anchor is inserted into the formwork. Consequently, a sliding strip, a soundproof strip, a bearing or compression strip or similar can be reversibly attached through a hook-mat to the resulting concrete element (Betonwerk Schuster 2016).
The research project "Klettbeton" (Raudaschl 2020) on the contrary, proposes the implementation of the hook-and-loop principle within the concrete element itself, that is, as a monolithic element. The basic objective is to produce a hook-and-loop component that has the properties of a concrete structural element in the context of material behavior, durability and material purity. Since hook-and-loop components are usually designed to be flexurally soft, it is also necessary to determine whether flexurally rigid hook-and-loop elements could exhibit hook-and-loop capability, but also how concrete might behave when loaded at the surface, as the depth of



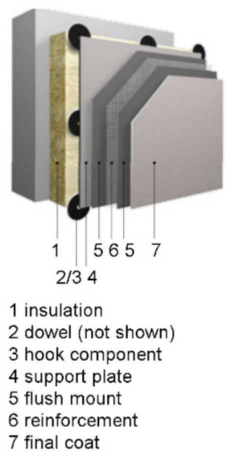


Figure 4. Fastening membrane as a protective exterior structural wrap (Tachauer et al. 2000), Components of the facade system StoSystain R (Sto Ges.m.b.H 2017)

engagement only amounts to a few millimeters (Fig. 5). In the research, a normal concrete was chosen, but optimizations of the concrete mixes (e.g. ultra-high-strength concrete UHPC) seem relevant for future development work. The formwork technique chosen was the 3D wax formwork technology due to their reusability (Kloft 2016), as in contrast to conventional plastic free-form formwork, the wax formwork layer can be melted down and entirely reused. Subsequently, any component equipped with the matching hook-and-loop element can be attached on site without any changes or further additional layers to the concrete element.
This kind of monolithic systems seem to be the most coherent path concerning their potential for a circular economy, as long as flexibility and durability are warranted. A further variation of this system could therefore be the development of controllable, de-activatable connection partners, since a bending-resistant hook-and-loop component runs the risk of being destroyed during dismantling.

4. CONCLUSIONS

Hook-and-loop can offer simple, clean and fast assembly processes while enabling damage-free and detachable connections. Their use could increase the share of building components that can easily be separated from each other, without noise and dust, and fed into the circular economy once a building reaches the end of its life. If properly standardized, it could become a uniform connection system that can basically be applied to any building element, independently of the supplier. However, up to now the use of hook-and-loop fasteners in the building industry has been driven by the demand either for reducing the labour and cost of montage during the construction phase or for increasing the variability (by replacing cladding, building services, etc.) during the life-span of the building. The fact that their use sometimes increases the possibility of disassembly and reuse of single elements is rather exceptional and therefore to be considered a positive side effect rather than a deliberate action. Moreover, adding hook-and-loop mats to conventional elements usually leads to extra layers (glue, bonding agents), thus aggravating the problems of waste segregation.
During the last decade though, new products and lines of research suggest a turning point towards circular economy as main focus. Following the previous analysis, we can identify three main strategies in order to pursue this goal: Firstly, the manufacture of hook-and-loop fasteners in the same material as the building element they will fixate, as that would reduce the number of materials to be segregated from currently three (element, glue, fastener) to two. Secondly, new developments

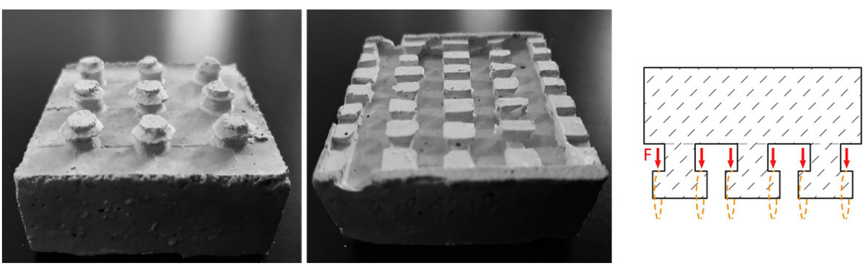


Figure 3. Velcro system in or on a building (Schaumburg 2012), Mounting the “Gecco-Wall” (Werner 2018)

in bonding technology aiming to minimize their negative impact on waste segregation, be it by reducing its share of the total product and/or by reducing its polluting potential in case of recycling. And thirdly, the development of fully monolithic systems, in which the hooks or loops are an intrinsic part of the building elements themselves. Recyclable materials that can be shaped with high precision seem best suited to fulfil this task.

Considering the high levels of performance that they have reached in other sectors and the increasing pressure to reduce raw materials and waste generation in the building industry, the further development of hook-and-loop fasteners construction systems seems definitely a strategy worth pursuing.

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