
AUTHOR ACCEPTED MANUSCRIPT

Originally published as Berker, T. and Woods, R. (2020), "Identifying and addressing reverse salients in infrastructural change. The case of a small zero emission campus in Southern Norway", *International Journal of Sustainability in Higher Education*, Vol. 21 No. 7, pp. 1625–1640. <https://doi.org/10.1108/IJSHE-12-2019-0354>

Republished in *ruination*, Vol. 1 (2026), 12 October 2026.

REPUBLISHED ARTICLE

Identifying and addressing reverse salients in infrastructural change. The case of a small zero emission campus in Southern Norway

Thomas Berker^{*}, Ruth Woods

Department of Interdisciplinary Studies of Culture, Norwegian University of Science and Technology, Trondheim, Norway

^{*} Corresponding author: thomas.berker@ntnu.no

Received 5 December 2019 · Revised 15 May 2020, 2 July 2020, 30 July 2020 · Accepted 31 July 2020

Collections **Metabole**

ABSTRACT

Purpose – The purpose of this paper is to demonstrate the relevance and use of the concept “reverse salient” in ambitious infrastructural change. Thomas Hughes, in his seminal study of socio-technical system building, observed that the elimination of “reverse salients”, i.e. subsystems that because of their limited performance hold back further development, was a central driver for creativity and innovation. It is argued that in sustainable infrastructural transformations, however, reverse salients that resist change are more often neglected than addressed.

Design/methodology/approach – Higher education institution campuses combine laboratory-like conditions and sufficient internal complexity to be used as test-beds for ambitious sustainable change in the built environment. In this article, a neglected barrier to the transformation of a small campus into a zero emission campus is revealed, described and addressed.

Findings – In terms of substantive findings, first, it is demonstrated how parts of infrastructures that – often for good reasons – have been neglected in efforts to reduce climate impacts can be identified with the help of a historical exploration of the site and through close collaboration with local facilities managers. Second, a temporary low-tech intervention is presented that addressed the critical problems related to these “reverse salients”.

Research limitations/implications – The limitations of a case study approach apply to this study. Particular caution has to be exercised in terms of generalisation. Moreover, the intervention would benefit greatly from stricter control and additional iterations of the intervention which have not yet been performed.

Practical implications – In addition to technology-focussed, top-down initiatives, which often struggle with actually reaching their ambitious goals in routine operation, neglected parts of campuses can contribute greatly to energy and emissions reductions. Moreover, it is demonstrated that and how local technical personnel has an important part to play in infrastructural transformations.

Originality/value – Concepts developed in the study of socio-technical system building have not yet been applied in the study and practice of sustainable infrastructural transformation. Their contribution is demonstrated. Moreover, living labs are notoriously difficult to evaluate. In this case study, processes and effects of an innovative living lab intervention are described and analysed. This enables a better understanding of restrictions and possibilities of experimenting in real-life settings.

Keywords Infrastructure · Climate change · Built environment · Renewable energy · Living lab

Paper type: Research paper

Please cite the version of record Berker, T. and Woods, R. (2020), “Identifying and addressing reverse salients in infrastructural change. The case of a small zero emission campus in Southern Norway”, *International Journal of Sustainability in Higher Education*, Vol. 21 No. 7, pp. 1625–1640. <https://doi.org/10.1108/IJSHE-12-2019-0354>

Introduction

At the turn of the second decade of the millennium, almost every higher education institution (HEI) has an explicit and often ambitious sustainability vision. This is the result of a more general mainstreaming of sustainability concerns in society (Berker, 2010), but it also reflects HEIs efforts to attract a generation which sees climate change as the most prominent issue facing their own future. These visions, very much in line with the early example of the Talloires declaration, consist of goals related to teaching, research and outreach activities, but they frequently also include the environmental footprint of HEIs’ own practices (Amaral *et al.*, 2015). To set “an example of environmental responsibility by establishing programs of resource conservation, recycling, and waste reduction at the universities” (Talloires Declaration, 1990), as it is formulated in the fifth point of the Talloires declaration, has become standard practice in the operation of many HEI facilities. A logical next step taken by many HEIs is to signal their sustainability commitment in the development of their campus infrastructures.

In this article, efforts are analysed to turn a small university college campus in Southern Norway into a zero emission campus that is largely self-sustained by renewable energy produced on site. The focus of this article is on those infrastructural elements that were so far neglected for various reasons. It is argued that, because of the interplay of different layers and elements of infrastructure, these omissions pose a problem for the performance of the whole campus. Bridging the gap between predominantly technical visions for sustainable campus infrastructures (Fonseca *et al.*, 2018) and the discussion of different forms of user engagement (Adomßent *et al.*, 2019), this approach is motivated by a growing concern for limitations of a purely technical approach: Recent advances in architecture, engineering and construction have given us the means to build climate-neutral buildings and neighbourhoods (Hestnes and Eik-Nes, 2017). However, there is mounting evidence of a performance gap between sustainability ambitions and actual performance in daily use (Mallory-Hill and Gorgolewski, 2018; Liang *et al.*, 2019). This is particularly the case when a focus on top performers and technical “hero stories” masks the overall less heroic day-to-day performance of the resulting infrastructure (Janda and Topouzi, 2015). This analysis is motivated and supported by a theoretical framework, presented more in depth in the next section, which views HEI campuses as heterogeneous infrastructures connecting old and new buildings, users and other infrastructural elements.

The question driving this paper is as follows:

Q1. *In cases in which it is not possible to renew all infrastructural elements, given that a campus’ environmental performance relies on the interplay between old and new elements, how can ambitious environmental goals still be achieved?*

The article starts with presenting the case for approaching campuses as socio-technical laboratories for experiments with sustainable change. Then, campuses are described as socio-technical infrastructures, in order to

present challenges and potentials related to campus development. After drawing up the theoretical framework and reflecting on methodology, a case study of a zero emission campus in Southern Norway is presented. A discussion of findings and practical implications concludes this article.

Campus as laboratory for infrastructural innovation

A campus is a microcosm incorporating most urban functions (Finlay and Massey, 2012). At its core, it provides infrastructures for teaching and research, which in this concentration cannot be found elsewhere. But, campuses also offer functions frequently encountered in urban spaces, such as office space, a variety of meeting spaces, it feeds its users in cantinas and cafes, it has recreational facilities, and in the case of on-campus student housing, it also incorporates residential spaces. All these functions, both in cities and in campuses are provided based on layered infrastructures that incorporate a large number of infrastructural elements, such as pipes, wires, walls, boilers, streets, etc. In what follows, based on the assumption that ambitious sustainable change also has to include radical infrastructural change, potentials and challenges of infrastructural change in HEI campuses are discussed.

Window and lab for experimentation with infrastructural change

HEI campuses, when conceived as microcosms in the sense of Finlay and Massey (2012), have the unique characteristic that they retain some of the complexity of larger infrastructures while reducing overall complexity. They are no island, obviously, and are connected to larger technical systems and political and social structures. But they still consist only of a limited number of connected buildings, functions, user groups and user practices. Moreover, these buildings, technologies and users are more homogeneous internally than in a regular city. And, their governance and organisational structure – also if it is conceded that it does not incorporate the “system archetype of a rational organization” (Sharp, 2002, p. 135) – is still less complex than that of a full-fledged city.

These characteristics of a bounded HEI campus provide support for the idea to approach it as a living laboratory for sustainable infrastructural change. As argued at length by Zen (2017), change in this bounded space offers ample learning opportunities integrating research, teaching and operations. While Zen (2017) focusses on the generation of new knowledge directly serving the internal goal of making the HEI more sustainable, the literature on living labs formulates additionally the broader goal of contributing to open innovation (Chesbrough, 2006) that serves more actors than the ones directly involved in the experiments.

One prominent example for this ambition is the definition of living labs promoted by the European Network of Living Labs (ENoLL) – often attributed with having played a central role in the concept’s broad diffusion since the mid-2000s – as “user-centred, open innovation ecosystems based on systematic user co-creation approach, integrating research and innovation processes in real life communities and settings” (ENoLL, 2016, p. 12). Applied to the case discussed here, HEI campuses can indeed be seen as “real life communities and settings” that can be expected to have a high innate capacity to “integrate research and innovation”. And if the goal is to experiment with sustainable change within a microcosm containing a less complex version of an urban infrastructure (Finlay and Massey, 2012), the expectation is reasonable that knowledge useful beyond the immediate campus context is produced. This, according to the socio-technical approach to infrastructures described more in detail in the next section, also touches upon another element of the ENoLLs definition of living labs: If infrastructures are seen as relational entities connecting technologies and users, changes are always “co-created” and a disregard of the social potential for sustainable change (Janda, 2014; Bull and Janda, 2018) is in the best case a missed opportunity but can also easily result in the kind of performance gaps observed so frequently in technology-centred change initiatives.

In summing up the potentials of HEI campuses for the goal of achieving sustainable infrastructural change, Vezzoli and Penin’s (2006) metaphors of “window” and “lab” are useful. The “lab” part is motivated by the ex-

pectation that “a university campus is a community very close to research and innovation; hence, this restricted community character could make it work as a ‘community-laboratory’” (Vezzoli and Penin, 2006, p. 75). In line with a socio-technical perspective, this expectation is extended with the observation that a campus is also bounded in terms of physical and organizational structures. At the same time, the campus can be seen as a “window”, “a campus can be at the same time an optimum window-shop to demonstrate sustainable innovations and to disseminate the new successful ones, to be later spread to society at large” (Vezzoli and Penin, 2006, p. 75).

Reverse salients in infrastructural innovation

The term “infrastructure” has emerged simultaneously with the large technical systems that were created during the 19th and 20th centuries (Hughes, 1988). This is no coincidence: made a priority in modern nation building, transport, energy and communication systems are the backbone of modern societies both in times of peace and war. During its first-century infrastructure development stubbornly led to ever more energy-intensive ways of organising production, transport and daily life in general (Nye, 1999). Based on fossil fuels and culminating in dreams of the atomic age in the 1960s (McKay, 1984), energy was seen as abundant and cheap. This changed profoundly with the oil shocks of the 1970s, nurturing for the first time an interest in more sustainable alternatives to existing infrastructures. It is remarkable that almost half a century later actual alternatives to fossil fuel-based energy and transport infrastructures are beginning to manifest themselves but are still considered to be a thing of the (near) future (Sørensen, 2015).

There are many reasons for the persistence of unsustainable infrastructures. Recent contributions have rediscovered the role of power in the form of active resistance enacted by the incumbents invested in the old socio-technical regimes and their infrastructures (Geels, 2014). But a closer look at what turns technologies into infrastructures shows that there are other, intrinsic reasons act as barrier against ambitious change by enforcing slow and only incremental change. In their classic catalogue of infrastructural characteristics, Star and Ruhleder (1996, p. 113) describe infrastructures as follows:

- visible only upon breakdown;
- transparent so that they do not have to be reinvented or assembled each time they are used;
- reaching temporally or spatially beyond a single event or one-site practice;
- learned as part of membership in a community of practice;
- linked with conventions of practice;
- embodiment of standards;
- built on installed base; and
- embedded inside other structures, social arrangements and technologies.

A common element of these characteristics is that they are about relations: between infrastructures, between technologies, between social conventions, communities of practice and the base upon which they are built. Being inextricably intertwined with so many heterogeneous elements, their radical change affects people and technology on many levels. In routine operation, the standardisation and conventional nature of infrastructures guarantee stability, which is achieved by balancing the generic nature of infrastructure with its use in specific contexts (Star and Ruhleder, 1996, p. 114). This balance is produced by the mutual shaping of local social practices and material structures that reach beyond a single site practice. Once this balance is achieved, its performance relies on tacit knowledge of its users, which is learned by using the infrastructure.

Infrastructures are built to last. The more they are embedded in other systems, the more expensive it is to change them because other elements have to be adapted to the change as well. Despite this general rule, infrastructures do change continuously, but they do so incrementally which reduces the scope and scale of a given transformation’s impact and allows for time to adapt to intended and unintended consequences of the change

that ripple through infrastructural layers. Neither are these changes usually uniform and result of a grand, comprehensive plan but rather the local result of repair, maintenance or cautious modernisation. But also well-meaning and ambitious plans of fundamental change have to account for the interrelatedness of infrastructural elements. While plans for sustainable infrastructure renewal – for instance, in the form of a vision for creating a smart city or a zero emission campus – can be holistic and all-encompassing, their implementation has to proceed incrementally. The most obvious reason for this is the high cost of infrastructure development, which applies to both new and the change of existing infrastructure. In the latter and much more common case, the renewal of an existing structure, the goal to minimise disruptions of existing operation additionally enforces incremental implementation.

In theory, given that the change is planned accordingly, incrementalism does not have to be a problem: piece by piece the elements of the infrastructure are modernised until the whole system is completed. In practice, however, the inertia of existing infrastructures not only enforces an incremental style of renewal but also results in islands of persistence, i.e. parts of the infrastructure which turn out to be very difficult to change. This may be caused by prohibitive cost, by externally imposed demands for preservation (e.g. listed buildings), or because of other prioritisations that are outside the infrastructure project's reach and scope.

Again, a co-existence of new and old elements does not have to be a problem. The most common way of dealing with such obstacles is to postpone their renewal while taking on first those elements that are easier to change. Then, as reasons that make some elements more difficult to change than others tend to persist, in most cases, this strategy leads to remnants of old infrastructures being incorporated into new ones. In principle, this incorporation can take two forms: First, it can happen passively and be left open for future rounds of renewal. In this case, detrimental effects for the performance of the infrastructure that result from it having to relate to the old element are ignored, as they will be eradicated later. Second, the old element can be incorporated actively. In this case, the goal is to reduce negative impacts, to balance these impacts through an increased performance of the new elements or – in the ideal case – to create synergies between the old and the new.

No matter which strategy is chosen, having to incorporate old elements in new, more performant infrastructures, because of infrastructures' relational nature, has the potential to reduce overall performance. The actual degree of impact will depend on the elements and their relation. The strategies of active or passive incorporation will allow us to deal with a certain amount of impact. If, however, the negative performance impact becomes big enough to considerably reduce the overall performance, these strategies start to fail. Particularly, in cases in which incorporation happens passively, a tolerable, temporary performance penalty turns into a problem for the sustainability ambition. One may accept that, for example, an old building for a while contributes unproportionally to the overall energy use at a campus. However, if there are no specific plans in place to deal with this problem (=active incorporation), it is here proposed to call this infrastructural element a "reverse salient".

This term, introduced by the historian Thomas Hughes, describes those elements that not only stay behind in socio-technical system building, but that in addition hold the development back. Hughes borrows the term from military historians, who use it to describe parts of a front that have fallen back and hold back the advancement of the army as a whole. In Hughes' historical analysis of the emergence of electrical infrastructures, the correction of such lagging elements is central to later phases of the development. His example is motor and capacitor used in direct-current grids that slowed down grid extension because it made long-distance transmission difficult until this problem was corrected by switching to alternate-current systems.

According to Hughes' historical study, before reverse salients can be eliminated, they have to be identified and be transformed to a set of "critical problems" that can be addressed:

Having identified the reverse salients, the system tenders can then analyze them as a series of critical problems. Defining reverse salients as critical problems is the essence of the creative process. An inventor or applier of science transforms an amorphous challenge – the backwardness of a system – into a set of problems that are believed to be solvable. (Hughes, 1988, p. 14)

Here, it is proposed to apply the strategy observed by Hughes to the sustainable renewal of infrastructures: To transform the “amorphous challenge” of persistent elements of existing infrastructures into “a set of problems that are believed to be solvable”. This requires to extend the attention from the crown jewels of a sustainable renewal, e.g. in the form of a particularly performant building or system, to also include those elements or layers that resist change.

Innovating campus infrastructures

According to Swearingen White (2003, p. 346), “grandiose plans for what were largely Utopian campuses” have been replaced by the post-war focus on rapid growth that has created “aesthetically incongruous campus conditions” that – as may be added in the context of this article – are only the visible tip of the iceberg of infrastructural incongruities. Except in those rare cases in which campuses are still developed from scratch, both pipes and wires under the ground and buildings above, will have to be transformed to fit into the new, more performant infrastructures, preferably without affecting the campus’ operation too much. In many cases, some of these elements will be as old as the university in question, and in some cases, in which a campus was created based on existing buildings that had another function before, even older.

In the following case study, such a case is presented, in which very ambitious sustainability goals were applied to an existing campus infrastructure. In what follows it is described how a reverse salient was identified, transformed into a “critical problem” and – with the help of local facilities managers – addressed through a temporary work-around.

In line with the perspectives presented above, the campus is approached as laboratory in the hope that both the methods applied and the solutions that were experimented with, yield knowledge that is not only useful for other similar campuses but also for the transformation of infrastructures in general.

Studying infrastructures as socio-technical entities

In methodological terms, questions prompted by the non-technical study of infrastructures have been extensively discussed by Star (1999) and Larkin (2013). Both wrestle with the distributed and relational nature of infrastructures described above. Larkin (2013) in his literature review of anthropological infrastructure research argues that infrastructures are particularly difficult to study for the anthropologist because they consist of flows that transcend single-site ethnographies. Following these flows, according to Larkin, leads the ethnographer easily away from the infrastructures into other fields “into which infrastructures bleed” (Larkin, 2013, p. 328), such as political processes or technological problems. To understand the “systemic” nature of infrastructures, he proposes a “retooling”, in which he recommends a systematic ethnographic study of the poetics, *aisthesis* and symbolic aspects connected to infrastructures and their development. For the purpose of transforming a campus infrastructure such a perspective enables us to remain close to infrastructures as the object of study while remaining open for its non-technical aspects. Star (1999) shares “tricks of the trade” of the study of infrastructure. She recommends to focus on master narratives, i.e. assumptions about functions and uses inscribed into infrastructural systems. In the case of campus infrastructure, an auditorium, for example, through its shape, location, acoustics and technical equipment tells a story about how lectures should proceed and what the role of lecturers and students are. In this sense, campus master plans are used to articulate visions about an HEI’s identity (Swearingen White, 2003, p. 344). Another “trick” shared by Star is to surface what she calls invisible work. Infrastructures are operated behind the backs of users by people that through their work with failures wherever they occur can have an in-depth understanding of the whole infrastructure and how its elements relate to each other. Harnessing this knowledge is an often neglected shortcut to a better understanding of an infrastructure – a neglect that results from the invisibility of the work done behind the scenes.

Together these methodological reflections have informed the case study presented here, in which the study of an infrastructural change was conducted by studying symbolic aspects (what does the infrastructure mean to its users?), invisible work (what do local facilities managers know?) and master narratives (what kind of story about higher education and sustainability is told by the infrastructure).

The ambition is to convey lessons learned from following the campus renewal over a period of a little over one year. In more traditional methodological terms, what is presented below is a case study connected to an experimental intervention. Following Flyvbjerg's (2006) recommendation to not conflate case study research with representative research or controlled experimentation, the focus is on learning. Consequently, the generalisation of findings that is attempted in the discussion and concluding remarks should be read as a cautious effort at conveying these lessons.

Zero emission campus at Evenstad

The study of efforts to transform an existing campus into a zero emission campus was funded by a research centre devoted to the creation of zero emission neighbourhoods. Both the centre and the case are described more in depth in the following sections. After that first perspectives and “tricks” introduced by infrastructure scholars that were described above are used. Then efforts to identify a reverse salient are described, how it was transformed into critical problems and how knowledge was created useful for addressing the critical problems.

Background: from buildings to neighbourhoods

Norway's economy relies heavily on the export of oil and gas while producing almost 100% of its domestic electricity with renewable hydropower. At the same time, Norwegians have one of the largest per capita electricity consumption in the world, which is to a large degree because of the use of electricity for building heating. One prominent Norwegian climate policy option in this situation is to free more of the renewable energy now used to heat buildings through energy efficiency measures in the built environment and to export it to other European countries reducing their dependence on fossil fuel export. This option, despite fierce resistance from energy producers (Kvellheim, 2017), has received considerable political support mainly through research investments and tougher energy demands written into the building code and its technical regulations. One result of this focus on reducing CO₂ emissions connected to the built environment is research on zero emission buildings and neighbourhoods, which offset CO₂ emissions connected to construction (including materials), operation and demolition with renewable energy produced on-site.

As part of these efforts, the overall goal of the Research Centre on Zero Emission Neighbourhoods (ZEN) in Smart Cities is “to enable the transition to low carbon society by developing sustainable neighbourhoods with zero greenhouse gas emissions” (fmezen.no). In addition to traditional engineering research, ZEN relies heavily on learning by doing, demonstrating and testing in nine pilot areas.

The site

Campus Evenstad is one of the ZEN centre's pilot areas. It is part of the Inland Norway University of Applied Sciences and is one of the three campuses that are part of the Faculty of Applied Ecology, Agricultural Sciences and Biotechnology. It is located in the heart of Østerdalen valley in the municipality of Stor-Elvdal, approximately 20 km south of the nearest town Koppang. The campus is spread over 61,000 m² with 17 buildings (10,000 m² gross internal area) serving uses: administration, education and sport, student housing and building operation. At the campus, some 70 employees are working and approximately 250 students are studying. The campus was also at the centre of pilot activity between 2009 and 2017 because a previous Centre for zero emission buildings (ZEB) developed one of its eight pilot projects, a new administration building, on campus. This

activity was performed in collaboration with Statsbygg a public sector administration company and advisor to the Norwegian Government in construction and property affairs. Statsbygg is also an official ZEN Centre partner.

The main aim behind the infrastructural transformation taking place at the pilot Campus Evenstad is emission reduction. This is planned to be achieved by development, implementation and optimisation of a smart energy management system, which helps to increase the share of renewable energy produced on-site. These energy sources are photovoltaics, a wood chips-based combined heat and power plant (CHP, Volter 40 Indoor, which produces about 0.4 kWh of electricity per kWh of thermal energy), solar collectors and bio-based boilers. Furthermore, batteries are located on-site and in a vehicle-to-grid (V2G) scheme, again to support the optimal use of self-produced energy and to reduce the share of energy imported through the grid (for more technical details, see Backe *et al.*, 2019).

The main activities conducted in 2018 are summarised in Table 1.

Table 1. Overview of methods/actions, time-frame and roles within the research activities in Campus Evenstad

Action	Role	Participants
ZEN partner workshop	ZEN partners, technical management, Evenstad, Campus administration and ZEN researchers	ca. 50 people
Living lab week, 05.03–08.03.2018. Lectures, workshops and four interviews	Campus administration, scientific personnel, students, technical management and ZEN researchers	ca. 30 people
Questionnaire	Campus administration, scientific personnel, students, technical management and ZEN researchers	27 people
Meeting 22.05.2018	Campus administration, technical management, building owner and ZEN researchers	12 people
Workshop 23.05.2018	Campus administration, scientific personnel, technical management and ZEN researchers	10 people
Experiment in the old administration building, 01.07.–01.08.2018	Technical management, scientific personnel and others with offices in the building	ca. 20 people
Publication of a blog post on a website for popular science dissemination, 12/2018	General public	
Interviews: Skype and face to face, November 2018	Scientific personnel with offices in the building	9 people (Offices 1–7 and Librarian 1–2)
Participant observation, 12.–16.11.2018	Office in the old administration building	Informal meetings, coffee breaks, lunch, 2–5 participants

Diving into the historical layers of Evenstad's infrastructure

Evenstad is made up of layers of infrastructures. The first foundations, now part of the high-tech energy systems currently tested by the ZEN Centre, appeared when Evenstad was farm in the 1800s. Some infrastruc-

tures, the river and the arable land, which supported the farm and its people, are still in place around the Campus. They are the reason why there was a farm at Evenstad and the farm is the reason why there is a campus at Evenstad, but their influence is now more symbolic than infrastructural or in the case of the river, challenging rather than functional. This character of once being a large farm also affects how Evenstad is connected to other infrastructures: it is isolated, which is very common for farms in Norway. It takes an hour and a half to reach other communities and their infrastructures. Its location makes it vulnerable to flooding, the local electricity network is not as stable as in urban areas, which challenges the introduction of electric cars, which were tested as part of an experimental V2G scheme.

A typical Norwegian farm is made of a number of buildings, the main house, a barn and storage spaces, houses for workers and family and for animals. Many of these buildings are still in place on campus. Læreboli-gen (teachers' house) now contains the offices of the technical staff, but was once a smaller farmhouse. Grisehuset (the pig house) is now a storage space. Other buildings are modern replacements of the original buildings, built on the same footprint and architecturally influenced by their original function. This includes the barn, which is now a teaching and study space, which has a large solar panel system on its roof. The main farmhouse is another one of these buildings. It burned down in 1987 and was replaced in 1989 by a post-modern version of the same building. Today, this building houses a canteen, library, laboratories and offices. Until recently, it was the main administration building on campus, but this function was replaced when Anne's house (a newly built ZEB) was completed in 2017.

The story of Evenstad is exemplary for the layered nature of infrastructures described by Star and Ruhleder (1996). It is a story of changes being added to the existing infrastructures, working with the limitations and potentials present at the site. It is also a clear example of infrastructural bricolage (Lévi-Strauss, 1966, p. 11). As the campus has grown and developed new buildings have appeared, e.g. student housing and Anne's house, which are connected to the existing network of pipes and wires providing, water, district heating and electricity and removing sewage. This network ties the buildings to the campus, holding them close to the old farm buildings and associated technical systems, such as the septic tank. The tank is located in the middle of the campus, between buildings. Another infrastructural element that could be expected to be hidden away but is located centrally and visible is the wood-chip gassification CHP plant "Volter", a recent addition as part of the efforts to make the campus a demonstration site for climate-friendly technologies. Its hum is all-present at parts of the campus as is the smell from the septic tank.

Identifying the reverse salient, the critical problem and a temporary solution

The first phase of the investigation which consisted of workshops with users and local operators and an anthropological study of the site and its use, originally aimed at creating user engagement among the campus' users. We quickly realised that users were not the most pressing problem for the site's infrastructural renewal. Instead, the local operators directed the attention towards a particular reverse salient.

The exploration into the campus' history, whose results were presented in the previous section, revealed that Evenstad's infrastructures are characterised by the site's historical depth which is mixed with cutting edge technical experimentation. This result resonated with the concerns described by local facilities managers when they were asked for which next steps would be important in the sustainable transformation of the campus. In interviews and conversations with them, it quickly became clear that, even though they spent much of their time to participate in the implementation of cutting edge zero emission infrastructural elements, their perspective covered the whole campus infrastructure. These local operators directed the attention towards the most important reverse salient, the old administration building, which is full of infrastructural inconveniences. Energy-wise, it is the most demanding building on campus. Every day, the old administration building uses a third of the energy requirements for the whole campus. This is as much as Anne's house (the zero emission pilot), the barn and the student housing (117 units) together during one day. The "mouse farm" and the other buildings on campus use the rest.

Over the whole year, local renewable energy production is able to serve the campus needs, but in terms of energy use reduction, which would help to shorten the periods in which energy import is necessary, the building is a technical challenge. Despite this fact, at the time of the writing of this article, there were still no plans in place to reduce this building's energy consumption. Instead, the focus was on efficient energy management and adding new technologies to the campus such as batteries and a V2G scheme (Figure 1).



Figure 1. Old administration building at Evenstad. *Source:* Picture by Ruth Woods

Transforming the reverse salient into critical problems

Interviewing the building's occupants revealed that there existed problems with indoor comfort in the building. The office windows have sunscreens installed but when the sunscreens are lowered, it is not possible to open the windows more than approximately 2 cm. As the offices are south facing, when the sun is shining, the offices become very warm. The ventilation system does not have the capacity to cool the offices enough and opening the window would help to ventilate naturally. The occupants with offices on the second floor of the building have to choose between keeping the sun out of the office and ventilating using the window. The problems with the building's indoor climate were associated with the story of infrastructural layers told earlier. The building was originally the main farmhouse on the Evenstad farm, built in the early 1800s when building standards were different and this affected the layout of a building. The building was south facing; this meant that the sun warmed the main living areas during the day and they were cooled at night. This old main building burned down in 1987 and was replaced with a building with clear architectural references to the previous building. It had similar size and footprint, the new building is also south facing. However, what worked in the old farm building did not function so well as an office building and the new technology installed in 1989, balanced ventilation, does not have the capacity to deal with the problem of overheating. The old infrastructural foundations have limited the functionality of the present-day campus.

The occupants stated that different kinds of sun shading or window system would help. During a workshop in May, two of the building users proposed installing roller blinds on the inside of the window as an immediate solution to the problem. A local operator said that improving the window systems on the building façade were on “the ‘to do’ list of measures, but low down on the list”. He added:

[. . .] the point is perhaps not to open the window, because then the effect of the ventilation system is reduced. The people who designed the building were not stupid. There was meaning behind it, but it’s no good when it gets so hopelessly hot.

These observations show how the building could become a reverse salient on the way to achieve zero emissions for the whole campus. As the local operators were busy with dealing with the cutting edge zero emission technologies installed more recently – in addition to “juggling” the tasks of normal operation (Aune *et al.*, 2009) – pressing problems connected to the offices’ indoor environment were moved down on the “to do” list. The same happened with the building’s abysmal energy performance: Researchers and owners involved in the infrastructure renewal focussed on the new elements, such as the new CHP plant or the ZEB, and planned around the old administration building.

It is reasonable to assume that improving both energy performance and indoor climate in the old administration building would have required additional investments, but resources were exhausted by a focus on world-leading technology and architecture and keeping the whole campus in working order. The critical problem posed by this building, thus, was that it fell between the chairs of high ambitions and the daily demands of regular operation, which made it “impossible” to change.

Addressing the critical problem

A solution to the critical problem would obviously either be the complete demolition and replacement of the building or at least a renovation, in which the ventilation system and sun shading are replaced with a system that provides a better indoor environment in a more energy-efficient way. However, both options were neither planned by the owner in the immediate future nor within the reach of the zero emission pilot projects. What *could* be done was to experiment with immediate measures that would not require additional funding but that would at least highlight the critical problems caused by the reverse salient of the old administration building.

The basic idea of the experiment, which was conceived by the local facilities managers, was to switch off heating and ventilation systems in the buildings during a four-week period in July 2018. This somewhat unconventional measure to save energy was motivated by two main considerations. Firstly, there are fewer people present on campus during the summer break. Secondly, instead of waiting for a costly deep renovation – or demolition – of the building that may or may not happen in the future, this measure was possible here and now without any financial investment.

When the experiment was proposed to the occupants and when the process was discussed and why the experiment was planned, they were sceptical. They maintained that the inconvenience that they would experience (we proposed that they did not use their offices at all but move temporarily to unoccupied offices at the campus during the four-week period, the heating and ventilation were shut down), would not be weighed up for by energy-saving benefits. In addition, any energy savings that are made during the shutdown benefit the university college, which has several campuses, centrally, not Campus Evenstad and not the building users. But they finally agreed to the experiment because they hoped that it would highlight the functional issues associated with the building.

Not surprisingly, the experiment succeeded to deliver the expected energy savings. Moreover, as the interviews conducted after the experiment show, the occupants evaluated the drastic measure as much as less demanding, in terms of comfort, than that expected. One informant told us that closing down the ventilation systems may even have had a positive effect on the building temperature. These findings are in line with theories of adaptive comfort that assume that the tolerance for higher indoor temperatures increases when out-

door temperatures are high (Nicol, 2011). The period during which the experiment took place indeed was characterised by a long heat streak. In addition, the fact that occupants already were dissatisfied before the experiment will very likely also have contributed to the tolerance for higher temperatures.

Unfortunately, time-consuming technical demands imposed by several cuts in the campus power supply occurring during the experiment meant that the technical staff did not have the time to follow up the experiment in the much more controlled ways that were initially proposed. There was, therefore, less quantitative data collected and it will be difficult to assess, for example, the impact the experiment had on productivity or the obligations following from the Working Environment Act.

In December 2018, the results of the experiment at Evenstad were presented first to ZEN researchers and the owner of Evenstad and then to a broader public through a blog post via the official ZEN communication channels. The lack of more specific quantitative data were deplored by the engineers from the ZEN centre. However, the representative from the owner organisation Statsbygg, who was in-charge of the ZEN pilot activities at Evenstad, reacted positively. He reported that Statsbygg, pending further, more controlled experiments, would certainly consider implementing the infrastructural change of switching off heating and ventilation in carefully selected buildings during periods where there are little use and high outdoor temperatures. Furthermore, this representative stressed that the inclusion of local building managers who know occupants and buildings well was important for Statsbygg (email received November 22, 2018). With a building portfolio of ca. 2.9 mio m² (2019), Statsbygg is a huge actor on the Norwegian market for non-residential buildings, so the potential energy savings, if the experiment's lessons are taken in use more broadly, are considerable.

Discussion

The study reported here yielded specific findings of emission reduction by showing that simple interventions targeting neglected parts of a campus infrastructure have a potential for dealing with reverse salients of the type encountered at this particular campus. Led by technical personnel on-site, in this study, sufficiency strategies were implemented (Herring, 2006) as intervention immediately applicable in the case of an old, energy intensive, non-residential building, whose improvement was otherwise low on the “to do” list. This was possible only during the summer months. During this time of year, occupants experienced the indoor climate in the building as bad anyway. Moreover, due to the summer holidays there is less occupancy.

Practices performed on HEI campuses, just like any practice (Shove, 2009), follow specific rhythms which in this way enable sufficiency strategies that could be designed more intelligently than in our case. To corroborate and refine these findings, more buildings in more contexts would have to be experimented with. These experiments would have to be conducted under more controlled circumstances, e.g. while studying the actual indoor environment instead of exclusively relying on the occupants' evaluations, from which we, however, have received encouraging signals.

While these findings are relevant and should be followed up on, the remainder will be used to present what was learned from applying a socio-technical perspective on infrastructures in zero emission experimentation with campus infrastructures.

Layers of infrastructure and how they matter

The historical study of layers of infrastructure at the site broadened the perspective from recent events in which high-tech zero emission solutions were implemented to a deeper history of infrastructural extension and redefinition of existing buildings. Using a perspective that had the whole campus as subject, all its buildings, its users and the meanings connected to the site, enabled the identification of the old administration building as reverse salient and revealed why and how this building had become a neglected part of the ambition to create a zero emission campus.

Invisible work in infrastructure change

Based on the relational approach to infrastructure, it is reasonable to assume that high degrees of “infrastructuralness” – in the sense of Star and Ruhleder’s catalog of what characterises infrastructures – will always present an obstacle to the co-creation of infrastructural change. In the Evenstad case, local actors willing to become engaged in the design of an infrastructural sustainability experiment *were* found in the shape of local building operators. This kind of “middle actor” (Parag and Janda, 2014) is located between the infrastructural change intention and built structures that carry meaning for the occupants (Aune *et al.*, 2009). In this context, it is notable that engineers from the outside experimenting with new technologies at the site had a decidedly different focus. The local actors focussed on the reverse salient, an old building that was left outside the focus of the previous implementation of cutting edge zero emission solutions while still being relevant if the whole campus energy consumption in routine operation is the object of change.

Implications

So what have we learned in this study in addition to that there is a potential contribution to climate mitigation related to low-tech sufficiency strategies? Concluding this article, implications will be outlined that point beyond the specifics of the case.

Firstly, obviously, not every HEI campus is a site with deep historical roots, but many are. In these cases, a careful exploration of layers of infrastructure yields insights into physical and symbolic sources of persistence in the face of intended change. In our case the combination of the following points produced a reverse salient:

- the preference for incremental change inherent in all infrastructures;
- much cared for meanings and place attachments related to a place’s history; and
- an one-sided focus on adding highly sustainable new elements to the campus.

These mechanisms are very likely also at work at many campuses and also in urban neighbourhoods more general.

Secondly, a small experiment was designed and implemented, which connected previously unrelated concerns of building occupants and the intended sustainable change. The input of a group of local actors, the technical personnel, was of great help. Star’s “trick of the trade” of studying infrastructures by looking at the invisible work needed to keep infrastructures working in the background can now be extended to be a “trick of the trade” in the identification of reverse salients in infrastructural change: to seek the support of groups that have intimate knowledge of the infrastructure in its technical form but that also deal with users. HEI campuses are usually large enough to have their own facilities management (FM) team on-site, which creates opportunities that should not be missed.

Concluding remarks

Between challenges of moving an infrastructure in all its heterogeneous complexity into a more sustainable direction and the potentials opened by HEI campuses to be “lab” and “window” for innovation, together with the technical personnel on-site, a site specific, temporal solution was implemented. But the case study together with its theoretical underpinnings has also generated new knowledge about infrastructural change processes, which, it is claimed here, has a potential to decrease the climate impact of HEI campuses and urban neighbourhoods in general. It consists of two main elements: Analysing layers of infrastructure and how they connect users and technology to identify “reverse salients” and “critical problems” and to enrol “middle actors” in the intended changes.

There remains much work to be done: More sufficiency experiments have to be conducted to enhance knowledge about, under which conditions, the drastic move to temporarily switch off technical systems is ac-

ceptable. The low-tech intervention implemented here led to massive energy savings, it was possible to be implemented without additional funding, and it yielded signals that the negative consequences that were expected did not materialize. These results are encouraging and should inspire the search for similar low-tech workarounds that complement the dominant focus on new technologies that promise to fulfil an HEI's sustainability mission.

Reverse salients as the one that was encountered in this study are likely to exist in more mature infrastructures that are subject of sustainable renewal. The more important message of this article therefore is that "reverse salients" should receive more attention in infrastructural development. Hughes' historical analysis of socio-technical system building has revealed that at a certain point of technological development, the care for those elements that lag behind the technological front becomes the main source for creative problem-solving. Reverse salients in infrastructure renewal deserve the same care and creativity.

References

- Adomßent, M., Grahl, A. and Spira, F. (2019), "Putting sustainable campuses into force", *International Journal of Sustainability in Higher Education*, Vol. 20 No. 3, pp. 470-481, doi: 10.1108/IJSHE-02-2019-0072.
- Amaral, L.P., Martins, N. and Gouveia, J.B. (2015), "Quest for a sustainable university: a review", *International Journal of Sustainability in Higher Education*, Vol. 16 No. 2, pp. 155-172, doi: 10.1108/IJSHE-02-2013-0017.
- Aune, M., Berker, T. and Bye, R. (2009), "The missing link which was already there: building operators and energy management in non-residential buildings", *Facilities*, Vol. 27 Nos 1/2, pp. 44-55, doi: 10.1108/02632770910923081.
- Backe, S., Sørensen, Å.L., Pinel, D., Clauß, J., Lausset, C. and Woods, R. (2019), "Consequences of local energy supply in Norway. A case study on the ZEN pilot project campus Evenstad", ZEN report 17. Sintef, available at: <https://sintef.brage.unit.no/sintef-xmllui/bitstream/handle/11250/2611937/ZEN%2bReport%2bno%2b17.pdf> (accessed 14 May 2020).
- Berker, T. (2010), "Dealing with uncertainty in sustainable innovation: mainstreaming and substitution", *International Journal of Innovation and Sustainable Development*, Vol. 5 No. 1, pp. 65-79.
- Bull, R. and Janda, K.B. (2018), "Beyond feedback: introducing the 'engagement gap'", *Building Research and Information*, Vol. 46 No. 3, pp. 300-315, doi: 10.1080/09613218.2017.1366748.
- Chesbrough, H. (2006), *Open Innovation*, Harvard Business School Press, Boston.
- EnoLL (2016), "Introducing ENoLL and its living lab community", available at: <https://forumvirium.fi/introducing-enoll-living-lab-community-2016/>
- Finlay, J. and Massey, J. (2012), "Eco-campus: applying the ecocity model to develop green university and college campuses", *International Journal of Sustainability in Higher Education*, Vol. 13 No. 2, pp. 150-165, doi: 10.1108/14676371211211836.
- Flyvbjerg, B. (2006), "Five misunderstandings about case-study research", *Qualitative Inquiry*, Vol. 12 No. 2, pp. 219-245.
- Fonseca, P., Moura, P., Jorge, H. and de Almeida, A. (2018), "Sustainability in university campus: options for achieving nearly zero energy goals", *International Journal of Sustainability in Higher Education*, Vol. 19 No. 4, pp. 790-816, doi: 10.1108/IJSHE-09-2017-0145.
- Geels, F.W. (2014), "Regime resistance against low-carbon transitions: introducing politics and power into the multi-level perspective", *Theory, Culture and Society*, Vol. 31 No. 5, pp. 21-40, doi: 10.1177/0263276414531627.
- Herring, H. (2006), "Energy efficiency – a critical view", *Energy*, Vol. 31 No. 1, pp. 10-20, doi: 10.1016/j.energy.2004.04.055.
- Hestnes, A.G. and Eik-Nes, N.L. (2017), *Zero Emission Buildings*, Fagbokforlaget, Bergen.
- Hughes, T.P. (1988), *Networks of Power: Electrification in Western Society 1880-1930*, Johns Hopkins University Press, Baltimore.
- Janda, K.B. (2014), "Building communities and social potential: between and beyond organizations and individuals in commercial properties", *Energy Policy*, Vol. 67, pp. 48-55, doi: 10.1016/j.enpol.2013.08.058.
- Janda, K.B. and Topouzi, M. (2015), "Telling tales: using stories to remake energy policy", *Building Research and Information*, Vol. 43 No. 4, pp. 516-533, doi: 10.1080/09613218.2015.1020217.
- Kvellheim, A.K. (2017), "The power of buildings in climate change mitigation: the case of Norway", *Energy Policy*, Vol. 110, pp. 653-661, doi: 10.1016/j.enpol.2017.08.037.
- Larkin, B. (2013), "The politics and poetics of infrastructure", *Annual Review of Anthropology*, Vol. 42 No. 1, pp. 327-343, doi: 10.1146/annurev-anthro-092412-155522.
- Lévi-Strauss, C. (1966), *The Savage Mind*, Weidenfeld and Nicolson.

- Liang, J., Qiu, Y. and Hu, M. (2019), "Mind the energy performance gap: evidence from green commercial buildings", *Resources, Conservation and Recycling*, Vol. 141, pp. 364-377, doi: 10.1016/j.resconrec.2018.10.021.
- McKay, A. (1984), *The Making of the Atomic Age*, Oxford University Press.
- Mallory-Hill, S. and Gorgolewski, M. (2018), "Mind the gap: studying actual versus predicted performance of green buildings in Canada", *Building Performance Evaluation*, Springer, Cham, pp. 261-274, doi: 10.1007/978-3-319-56862-1_20.
- Nicol, J.F. (2011), "Adaptive comfort", *Building Research and Information*, Vol. 39 No. 2, p. 105, doi: 10.1080/09613218.2011.558690.
- Nye, D.E. (1999), *Consuming Power: A Social History of American Energies*, MIT Press.
- Parag, Y. and Janda, K.B. (2014), "More than filler: middle actors and socio-technical change in the energy system from the 'middle-out'", *Energy Research and Social Science*, Vol. 3, pp. 102-112, doi: 10.1016/j.erss.2014.07.011.
- Sharp, L. (2002), "Green campuses: the road from little victories to systemic transformation", *International Journal of Sustainability in Higher Education*, Vol. 3 No. 2, pp. 128-145, doi: 10.1108/14676370210422357.
- Shove, E. (2009), "Everyday practice and the consumption and production of time", in Shove, E., Trentmann, F. and Wilk, R. (Eds), *Time, Consumption and Everyday Life*, Berg, Oxford, pp. 17-34.
- Sørensen, K.H. (2015), "From 'alternative' to 'advanced': mainstreaming of sustainable technologies", *Science and Technology Studies*, Vol. 28 No. 1, pp. 10-27.
- Star, S.L. (1999), "The ethnography of infrastructure", *American Behavioral Scientist*, Vol. 43 No. 3, pp. 377-391.
- Star, S.L. and Ruhleder, K. (1996), "Steps toward an ecology of infrastructure: design and access for large information spaces", *Information Systems Research*, Vol. 7 No. 1, p. 25.
- Swearingen White, S. (2003), "Sustainable campuses and campus planning: experiences from a classroom case study at the University of Kansas", *International Journal of Sustainability in Higher Education*, Vol. 4 No. 4, pp. 344-356, doi: 10.1108/14676370310497561.
- Talloires Declaration (1990), available at: <http://ulsf.org/wp-content/uploads/2015/06/TD.pdf> (accessed 14 May 2020).
- Vezzoli, C. and Penin, L. (2006), "Campus: 'lab' and 'window' for sustainable design research and education: the DECOS educational network experience", *International Journal of Sustainability in Higher Education*, Vol. 7 No. 1, pp. 69-80, doi: 10.1108/14676370610639254.
- Zen, I.S. (2017), "Exploring the living learning laboratory: an approach to strengthen campus sustainability initiatives by using sustainability science approach", *International Journal of Sustainability in Higher Education*, Vol. 18 No. 6, pp. 939-955, doi: 10.1108/IJSHE-09-2015-0154.

Further reading

- Callon, M., Lascoumes, P. and Barthe, Y. (2011), *Acting in an Uncertain World: An Essay on Technical Democracy (inside Technology)*, The MIT Press.
- Preisner, W.F.E., Vischer, J.C. and White, E.T. (Eds) (1991), *Design Intervention. Toward a More Humane Architecture*, Van Nostrand Reinhold, New York, NY.

About the authors

As at original publication (2020).

Thomas Berker is Professor in Science and Technology Studies at NTNU's Centre for Technology and Society. In more than 70 publications, he has covered a wide array of topics related to end-user acceptance of new technologies, including the role of users in sustainable innovation, in-depth accounts of how end-users creatively sabotage well-intended technologies, and how technology design can contribute to a better quality of life for its users. Originally trained in the sociology of technology and of work (PhD awarded in 2000), from early on, his research has focussed on the various ways in which end-users engage with digital technologies and buildings. Since 2004, he has conducted most of his research in close collaboration with engineers and architects. Currently, he leads NTNU's Centre for Technology and Society and is involved in research projects among others on living labs in zero emission neighbourhood development, everyday acceptance of circular economy, the role of user-driven innovation in regional development and the design of productive work environments.

Ruth Woods is Post-doctoral Fellow connected to the Research Centre on Zero Emission Neighbourhoods (ZEN) in Smart Cities, a researcher at the Department of Interdisciplinary Studies of Culture at NTNU and Senior Researcher at the research institute, SINTEF Community. Woods is Social Anthropologist and is particularly interested in the interaction between people, buildings and technology. She has studied a wide range of contexts from shopping centres and care homes to houses and zero emission pilot buildings. Her

current research focusses on the establishment of living labs in ZEN. This is followed up by an interest in response of citizens and building users to being part of zero emission concept and to their involvement in living labs.

Funding. This research was funded by the FME Research Centre on Zero Emission Buildings in Smart Cities (FME ZEN).

Licence. This author accepted manuscript is deposited under a Creative Commons Attribution Non-commercial 4.0 International (CC BY-NC) licence. This means that anyone may distribute, adapt, and build upon the work for non-commercial purposes, subject to full attribution. If you wish to use this manuscript for commercial purposes, please visit Marketplace.

Version of record. © 2020 Emerald Publishing Limited. Berker, T. and Woods, R. (2020), "Identifying and addressing reverse salients in infrastructural change. The case of a small zero emission campus in Southern Norway", *International Journal of Sustainability in Higher Education*, Vol. 21 No. 7, pp. 1625–1640. <https://doi.org/10.1108/IJSHE-12-2019-0354>