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Innovation in the fringes of software ecosystems: the role of socio-technical generativity*

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ABSTRACT
Understanding the way information systems grow and change over time and the role of different contributors in these processes is central to current research on software development and innovation. In relation to this, there is an ongoing discourse on how the attributes of software platforms influence who can innovate on top of them and the kind of innovations possible within the larger ecosystem of technologies and people these platforms are part of. This discourse has paid limited attention to innovation unfolding in the fringes of the ecosystems peripheral to and disconnected from where the central software components are developed and where the resources necessary for digital innovation are scarce. Drawing upon Zittrain’s characteristics of generativity and Lane’s concept of generative relationships, the key contribution of this paper is a socio-technical perspective on innovation and generativity in this setting. We build this perspective of socio-technical generativity based on a case study of software innovation activities in Malawi on top of the health information system software platform DHIS2 developed in Norway. This case illustrates how the technical attributes of the platform played a key role in concert with human relationships in shaping innovation activities in Malawi.

KEYWORDS
Generativity; generative relationships; ecosystems; fringes; digital innovation; Malawi

1. Introduction

Information systems are no longer developed and managed as stand-alone and monolithic systems, but are parts of larger ecosystems (Hanseth & Lytytinen, 2010). Aligning with and becoming parts of ecosystems is a new and different challenge for system developers (Sommerville et al., 2012). It involves grappling with the complexity that emerges from the heterogeneity of the multiplicity of systems, functionalities and actors involved. These are the challenges associated with large-scale and complex information systems. State-of-the-art agile and user-centered methods as well as advanced programming tools and frameworks all seek to cope with complexity. However, most of them are doing so in a software-centric fashion and fail to address the broader heterogeneity of systems, users and developers involved in digital innovation (Yoo, Boland, Lytytinen, &
In this paper, our aim is to contribute to addressing this gap by bringing a stronger focus on the opportunities for innovation in the fringes of ecosystems. Fringes in our case relate to spaces where innovation activities unfold far away from and thus disconnected from the context where the central software components (typically, a software platform) in the ecosystem are developed. These are contexts where resources and human capacity for digital innovation are scarce.

The different roles of different contributors and components are a key part of current digital innovation discourses. For example, the success of digital platforms (such as App-Store) has triggered the curiosity of researchers and many discussions concerning the different roles and the relations between platform owners and app developers (see, e.g. Elaluf-Calderwood, Herzhoff, Sørensen, & Eaton, 2011; Yoo et al., 2012). With a similar focus, Tiwana, Konsynski, and Bush (2010) define a software platform as a software-based system with an extensible codebase that provides core functionality shared by modules (applications) that interoperate with it. The software platform and the modules connecting to it comprise a platform-based software ecosystem. These ecosystems represent a departure from traditional software development as they depend on leverage and rely on the expertise and initiative of a diverse developer community to generate new capabilities (innovations) on top of platforms.

While software platforms and ecosystems have attracted a general research interest toward architecture, governance and digital innovation, these topics do not have a prominent position in the ICT for development literature and debates (Nielsen, 2017). While a special issue on ICT ecosystems was published in the Information Technology for Development journal in 2016, the focus was on how ICTs are embedded in socio-economic contexts (see, for example, the editorial by Diga & May, 2016). The emphasis was limited to the context in which ICTs are used, a focus also reflected in other discussions on innovation and the role of ICT in transforming development (see, e.g. Qureshi 2013). This paper extends these discussions by studying a software platform, how it is contextualized in the fringes and in particular how innovation is unfolding on top of it in a developing country setting and as a part of software ecosystems composed of globally distributed participants.

Different factors influence the way in which different software platforms spur innovation and fuel entrepreneurship. Attributes of the platforms (e.g. their accessibility, transferability and adaptability) will influence who can innovate and the kind of innovations technically possible and economically viable. Zittrain (2006) has ventured deeply into these matters and based on studying the Internet, he coined its key success factor as its generativity. He argues that the essential flexibility of Internet as a platform is not limited to its modularity and decentralized network architecture, but also the way in which it enables and leverages innovation performed by a broad range of contributors. These mechanisms can be exemplified with the DHIS2 software platform discussed in this paper where innovation is leveraged based on a sophisticated and rich RESTful Web API that allows extensions of functionality. While discussing the way in which the capacities of different technologies and platforms are influencing innovation is fertile, Zittrain in his definition of generativity attributes innovative capacity primarily to the technology. But while some platforms may be understood to enable and facilitate more innovation than others, innovation is nevertheless a human activity. We argue, concurring with Lane (2011), that innovation is always a collective and social
activity. And in particular in a setting of complexity and uncertainty, identities and attributes of technology develop and change through collectives and based on human relationships.

The focus in this paper is innovation on top of a software platform and with a particular focus on the people located in the fringes of a software ecosystem. We argue that discussing innovation in this setting with a generativity perspective offers us a venue to understand how the social activity of innovation is technologically framed and vice versa. Our attempt is to answer the following research question: *How can our understanding of generativity be framed to provide a holistic account of both technological and social factors that constrain and enable innovation in the fringes of software ecosystems?* The main contribution of this paper is our concept of *socio-technical generativity*. We build this concept by drawing together the technology-focused work of Zittrain and the socially oriented work of Lane. We discuss this holistic perspective based on a study of innovation activities in Malawi based on the open-source health information system software platform DHIS2 developed by the University of Oslo, Norway (see www.dhis2.org). Through the discussion, we also develop our concept of software ecosystem fringes. We show that even if the technical attributes of the software platform play crucial roles in fostering and shaping innovation, it yields little if any innovation in the fringes of its ecosystem if not backed by strong human relationships.

In the next section, we introduce our concept of generativity and point to existing research in this area. In Section 3, we describe our research approach before we present our case study in Section 4. In Section 5, we analyze the case by using our concept of socio-technical generativity and we finally draw theoretical and practical contributions in Section 6.

## 2. Generativity

In this section, we introduce two different perspectives on generativity, one that is technology-oriented and another focusing on social relationships. Based on these perspectives, we argue for and suggest a holistic and integrated perspective on generativity: socio-technical generativity.

### 2.1. Generative technologies

The concept of generativity has attracted attention in information systems research, with a particular focus on innovation with respect to information infrastructures and other forms of digital artifacts (see, e.g. Henfridsson & Bygstad, 2013). Generally, generativity is defined as an ability or capacity to generate or produce something (Avital & Te’eni, 2009). More particular, generativity is defined as the overall capacity of a technology or a system to be flexible and malleable by diverse groups of actors and in unanticipated ways (Eck, Uebernickel, & Brenner, 2015; Zittrain, 2006, 2008). The underlying idea is that the success of a technological platform hinges on the participation of independent third-party actors in the generation and production of innovations. The possibilities and incentives for these third parties to engage in innovation depend on the generative capacity of the platform. According to Zittrain (2008), there are five key characteristics of the generativity of technologies:
Leverage: The extent of which the productivity of an actor using the technology is increased as compared to not using it. A technology with good leverage makes difficult tasks easier.

Adaptability: The potential of the technology to be adapted for use in different contexts than the one it was designed for.

Ease of mastery: How easy it is for an actor to understand a technology as well as the amount of effort required to adapt it.

Accessibility: How easy it is (or barriers) to obtain access to a technology, along with the tools and information necessary to achieve its mastery. This includes the cost of acquisition, regulation and secrecy by technology producers to maintain control, which are typical barriers.

Transferability: The ease of which technologies from one context can be conveyed to and re-appropriated in other contexts.

This understanding of the role of technology platforms in innovation is reflected in discussions related to the “essence” of the Internet. This “essence” is seen as important among scholars discussing the regulation of cyberspace. These scholars point to the key qualities of the Internet that are maintaining the speed and scope of innovations it has triggered – regarding both the Internet itself and its use. Lawrence Lessig (2001) has stressed the importance of the location of functions close to the application that uses the function, the so-called end-to-end architecture, originally proposed by Saltzer, Reed, and Clark (1984). This is a central principle to provide flexibility by systems design. The point this principle is making is that functionality in networks only can be appropriately implemented if based on knowledge – knowledge that only exists close to the applications standing at the endpoints of a network. And network growth is based at the endpoints and the applications, and not as a centralized activity. Both Lessig (2001) and David (2001) exemplify this argument by illustrating the Internet as a network where intelligence is in the endpoints. Because the Internet is not optimized for any application but opens for the unexpected and surprising, innovations can flourish without changes in standards or the network itself. The important role of the end-to-end architecture in the success of the Internet is also underscored by historian Janet Abbate (1994, 1999) in her analysis of the history of the Internet and this relationship between the end-to-end architecture and innovation has also been analyzed by Barbara van Schewick (2012). The discussion about the importance of the Internet’s end-to-end architecture has more recently turned into a broader one also focusing on the importance of platform-based architectures and the evolution of platform-centric ecologies, typical examples being the iPhone and Android platforms and their respective ecologies (Gawer, 2011; Tiwana et al., 2010). Yochai Benkler (2006) extends the end-to-end argument by underscoring the mutual dependence of the end-to-end architecture of networks and (easily) programmable terminals. Benkler bases his argument on contrasting programmable computers and appliances. An appliance is a device with a limited and well-defined set of functions which (normally) cannot be modified after the users have bought it. Typical examples include washing machines, radios and cars. Such devices have computers inside, but their software cannot be modified by its users. Benkler is worried that several proposals for increasing security and preventing harmful use of the Internet, i.e. cyberspace regulation, will constrain the Internet users’ ability to program their computers, i.e. turn
them into appliances. An example of this is found in the proposed “trusted computing”
technology and how this may be implemented and ways in which it might be enforced
by law.

Inspired by the Internet and lately also platforms for mobile phone apps and digital
innovation in general, there is a growing technology-oriented literature on generativity.
This literature attempts to discern and improve our understanding of the characteristics
and capacities of technologies that turn them into platforms for innovation.

2.2. Generative relationships

Framed within organizational thinking, David A. Lane (2011) presents a different, yet comp-
lementary we argue, theory of innovation built around complexity and the cognitive pro-
cesses involved in innovation. This theory consists of two main concepts: exaptive
bootstrapping and generative relationships. The concept of exaptive bootstrapping
describes how technologies emerge and evolve. Lane describes these processes as a five-
step algorithm driven by positive feedback (Lane 2011, p. 69): (1) new artifacts are designed
to achieve some particular attribution of functionality; (2) organizational transformations are
constructed to proliferate the use of tokens of the new type; (3) novel patterns of human
interaction emerge around these artifacts in use; (4) new attributions of functionality are
generated – by participants or observers – to describe what the participants in these inter-
actions are obtaining or might obtain from them; and (5) new artifacts are conceived to
instantiate the new attributed functionality. Lane (2011, p. 71) claims that “the most impor-
tant cognitive process in innovation is the generation of new attributions” and that “the
most important communication process involves the aligning of attributions among
agents.” Accordingly, Lane understands innovation as a collective and social activity.
Under situations of uncertainty and change, identities and attributions change, and
agents need to track these changes carefully in their attributions of the identity of the sig-
nificant agents and artifacts in their world. The process of monitoring and interpreting iden-
tities requires discourses with other agents. These discourses are channeled through the
agents’ informational and interpretive social networks. And from these networks, generative
relationships emerge.

New attributions arise in the context of a particular kind of relationship among agents
which Lane calls generative. Generative relationships may link actors from the same firm,
different groups of actors from more than one organization engaged in joint projects, or
agents working together under the auspices of a market system. And the generative
potential of relationships among agents and their modes of interaction depend according
to Lane (2011) on five characteristics:

- **Aligned directedness**: Interactions among agents are focused on achieving similar
  transformations.
- **Heterogeneity**: Even if having the same overall aim to support a stable system, to
  succeed, innovative agents have to seek out and build strong relationships with
  other agents that differ substantially in terms of, e.g. competence, social positions
  and access to resources.
- **Mutual directedness**: The group of heterogeneous actors, which have different experi-
  ences and perceive the world differently, engage with each other in a way where
they see each other’s worldview and experiences as a resource rather than assuming the world views different from one’s own to be wrong – which often happens.

- **Appropriate permissions**: What the individual actors are allowed to do, i.e. what Lane calls permission structures that shape appropriate permission to engage in innovation.
- **Action opportunities**: Whether the actors have the possibility to engage with one another in interactions that result in transformations not just in their own attributions, but in the structure of agent-artifact space.

### 2.3. Socio-technical generativity

The concepts of generative technologies and generative relationships are both focused on innovation. And they both concern how innovation is emergent and the outcome of human actors exploring new ideas and opportunities. They address the challenge of understanding how innovation happens in complex settings and how different technological and social environments in different ways enable innovation. At the same time, the generative technologies perspective primarily focuses on attributes of technologies as the enabler for innovation, where the generative relationships perspective primarily focuses on the attributes of the organizational setting of human actors involved in innovation and the relationships between these human actors. In this way, they are complementary. While different technologies have different capacities to facilitate innovation, innovation cannot be seen as independent of human activity. And the activities of humans engaged in innovation will be influenced by other humans as well as the properties of the technology they are working with. This complementarity has also been picked up by Avital and Te’eni (2009) when they argue that the extent to which innovation will take place depends on an appropriate combination of a generative technology and a generative collective of users and developers. When these elements are matched in a successful way, there is a generative fit between the two. This is socio-technical generativity.

Drawing from the concepts of generative technologies and generative relationships, we summarize the attributes of socio-technical generativity in **Table 1**. The attributes fall into two dimensions: the social dimension concerning how social relationships can be conducive for innovation and the technical dimension concerning the capacity of technologies.

<table>
<thead>
<tr>
<th>Socio-technical generativity</th>
<th>Technology capacities</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Aligned directedness</strong></td>
<td>Leverage</td>
</tr>
<tr>
<td>Focus on achieving the same transformation</td>
<td>Increasing productivity for the users</td>
</tr>
<tr>
<td><strong>Heterogeneity</strong></td>
<td>Adaptability</td>
</tr>
<tr>
<td>Complementarity in competence, social positions and access to resources</td>
<td>Potential to be used for what it is not designed for</td>
</tr>
<tr>
<td><strong>Mutual directedness</strong></td>
<td>Ease of mastery</td>
</tr>
<tr>
<td>Appreciation of differences and complementarities</td>
<td>Limited efforts to understand and adapt</td>
</tr>
<tr>
<td><strong>Appropriate permissions</strong></td>
<td>Accessibility</td>
</tr>
<tr>
<td>Permissions to innovate</td>
<td>Ease to obtain access and master</td>
</tr>
<tr>
<td><strong>Action opportunities</strong></td>
<td>Transferability</td>
</tr>
<tr>
<td>Opportunity to change own and influence others’ attributions of technology</td>
<td>Ease to convey from one context to another</td>
</tr>
</tbody>
</table>
in supporting and promoting innovation. These two dimensions of socio-technical generativity will mutually influence each other. In this interplay, the two dimensions can positively or negatively influence as well as mutually reinforce each other. For example, a flexible permission regime around a software platform increases its adaptability and accessibility. At the same time, unregulated change resulting from a very permissive regime can result in innovations that are not compatible with a generic platform and thereby negatively affect the transferability of the resulting innovations. Ensuring transferability of innovations entails having a well-regulated permission regime to ensure compatibility of emerging innovations. With this interplay in mind, our hypothesis is that this socio-technical perspective on generativity will enable us to better analyze, understand and promote innovation on top of software platforms. In Section 5, we apply this perspective to discuss our case study of local innovation in the fringes of the DHIS2 software ecosystem in Malawi.

2.4. Socio-technical generativity and the fringes of software ecosystems

ICTs are now available and affordable for large populations also in developing countries, and Yoo, Henfridsson, and Lytytinen (2010) have argued that digital technology: “... has democratized innovation and almost anyone can now participate...” (p. 726). We define fringes of software ecosystems as contexts peripheral to and disconnected from the context where central software components are developed and where the resources necessary for digital innovation typically are scarce. These resources include human capacity and social relations. While also these spaces are increasingly connected in terms of high-quality and affordable Internet access, they continue to be weak in terms of human capacities, they are likely to be disconnected from innovation networks and they lack generative social relationships. Enabling innovation in such contexts will put high demands on the generative capacity of the technology and provide ways in which those located in the fringes can tap into and contribute toward generative social relationships. Software development and innovation can be seen as unfolding in a complex environment in which multiple software components exist and interact (see Manikas & Hansen, 2013; Tiwana et al., 2010). Such ecosystem perspectives are based on and understanding of symbiotic relationships between the different components and often the central position of a software platform (Gawer, 2011). Our concept of fringes turns the attention away from the role of the central platforms and the focal point becomes the periphery of software ecosystems.

3. Research approach

In the next section, we introduce a case study of the implementation and use of DHIS2 in Malawi. Developed by the University of Oslo in Norway, DHIS2 is a flexible, free and open-source-based software platform designed to support the collection, aggregation and visualization of routine health indicators in developing countries. DHIS2 is highly configurable and customizable, and has an extensive API allowing for integration with other systems and development of apps on top of it by third parties.

We have studied the introduction, implementation and later innovation initiatives on top of DHIS2 in Malawi. We analyze this process based on a perspective on innovation
as not only influenced by technical artifacts and their trajectories, but also occurring through a negotiation process involving a heterogeneous network of human and technological actors (Law, 1999). Our research design traces the technical components involved, the role and intentions of innovators and designers locally and globally, and how this is reflected in how the technology is used (Faraj, Kwon, & Watts, 2004), focusing on “recognising the depths of interdependence of technical networks and standards, on the one hand, and the real work of politics and knowledge production on the other” (Bowker & Star, 2000, p. 34).

The case study reported here is based on 19 informal and in-depth interviews with managers and technical personnel in 6 different organizations related to the implementation of DHIS2 and related innovations in Malawi (summarized in Table 2). The organizations included the Central Monitoring and Evaluation Division (CMED) in the Ministry of Health under whose custody DHIS2 falls; the HIV/AIDS department which hosts other health information systems for the Ministry of Health; the local organization of DHIS2 experts HISP Malawi, University of Malawi and GIZ/EPOS Health Management providing local technical support on DHIS2; and DTREE and Baobab Health Trust which are working toward integrating their electronic health solutions with DHIS2. The interviews were focused on how the different actors use and understand DHIS2 and how they contributed to its implementation and related innovations in Malawi. Where consent was granted by the respondent, the interviews were recorded and later transcribed. Otherwise, written notes were taken. While the entire set of interviews provide the background and setting of local innovation, this paper particularly draws upon interviews focusing on the implementation and innovations on top of the DHIS2 platform. These “innovation episodes” around DHIS2 in Malawi include DHIS2 integration attempts, DHIS2 reconfiguration and third-party application development exemplified by the League Table App.

In addition to interviews, document reviews were carried out to trace the implementation and “innovation episodes” related to DHIS2 in Malawi. Document reviewed included research reports, websites (e.g. www.hismalawi.org.mm), minutes of planning and review meetings, and emails from the stakeholders mailing group. Furthermore, participatory observation was carried out whereby one of the authors is an active participant in an ongoing DHIS2 reconfiguration project in Malawi. The data collected from interviews, documents and observations combined were used to identify the “innovation episodes”

<table>
<thead>
<tr>
<th>Organization</th>
<th>No. of interviews</th>
<th>Designation of interviewees</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ministry of Health/CMED</td>
<td>6</td>
<td>Director, CMED</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Chief Technical Assistant, HMIS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Chief statistician</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DHIS2 Technical Assistants (3)</td>
</tr>
<tr>
<td>HISP Malawi</td>
<td>3</td>
<td>Board members (3)</td>
</tr>
<tr>
<td>Baobab Health Trust (BHT)</td>
<td>4</td>
<td>Executive Director</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Software Development Manager</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DHIS2 Integration Team Members (2)</td>
</tr>
<tr>
<td>University of Malawi</td>
<td>1</td>
<td>HISP Malawi Representative</td>
</tr>
<tr>
<td>Ministry of Health/HIV–AIDS Department</td>
<td>2</td>
<td>Technical Assistant, Systems Administration (I-TECH)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Technical Assistant, Statistics (I-TECH)</td>
</tr>
<tr>
<td>DTREE International</td>
<td>1</td>
<td>Project Manager</td>
</tr>
<tr>
<td>GIZ/EPOS Health Management</td>
<td>2</td>
<td>Senior Technical Advisor, HMIS Strengthening Programme</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DHIS2 Technical Assistant</td>
</tr>
</tbody>
</table>
and these episodes and their context were used to focus the further analysis. Along the analysis, we built our socio-technical perspective on generativity and understanding of fringes, and its dimensions were further used to support and guide the analysis and discussion.

4. The case of DHIS2 in Malawi

4.1. The process of implementing DHIS2 in Malawi

DHIS2 is centered on supporting the collection, aggregation and visualization of routine health data, or so-called health indicators. It is developed by the Health Information Systems Programme at the University of Oslo (HISP UiO) based on the support from international donors. It has over the recent years developed into a de facto standard in developing countries and is widely used by Ministries of Health, health programs, donors and NGOs. In some countries, DHIS2 is implemented as the national health information management system.

DHIS2 has a sophisticated and rich RESTful Web API that allows extension of functionality through new innovations using Web technologies such as JavaScript, CSS and HTML5. These can be additional software modules that sit side by side the DHIS2 core modules or applications that run on top of it. From previously being a software system developed by the core team of developers in Oslo alone, the strategy behind DHIS2 is today one of open innovation. Extensions with apps are expected to be developed by a wide audience of developers participating and contributing to the DHIS2 software ecosystem globally. Malawi is a part of this ecosystem, but also very much located in its fringes.

DHIS2 was introduced in Malawi as part of a health management information system (HMIS) strengthening program initiated in 1999. A prime motivation behind these efforts was an identified lack of reliable information for health services planning and management due to, among other things, the existence of a number of different information systems belonging to vertical health programs. This fragmentation made access to health programs’ data difficult across programs and geographies. Data remained within the different information systems of the different health programs and in separate, silo-systems. Between 1999 and 2002, an HMIS review funded by the Dutch Government was carried out. The review led to the implementation and launch of an early version of DHIS2 (DHIS) as the national Health Information System in January 2002. At the time, DHIS was a desktop-based application based on the Microsoft Access platform. Being a desktop application, it did not support shared access to information as noted by a Director at CMED: “… sharing data to geographically distant stakeholders was still a challenge.” As a result, fragmentation continued, characterized by the continued existence of paper systems and multiple computerized systems. Furthermore, DHIS was not scalable due to the use of proprietary software which entailed license fees for each workstation where it was installed. A different solution was required to improve the health information system in Malawi. In 2005, HISP UiO made the first release of the open-source and web-based DHIS2.

In Malawi, efforts to replace DHIS with DHIS2 commenced in 2009 with a pilot project targeting three health districts. In this process, new challenges emerged and were handled. First, the CMED of the Ministry of Health (MoH) under whose jurisdiction
DHIS2 falls lacked the requisite technical capacity and human resources to implement and rollout DHIS2. This was due to the fact that the CMED organization is dominated by economists and statisticians and without any ICT staff. MoH, like any other ministry in the Malawi Government, is allocated ICT staff by the Department of e-Government. This staff is typically dedicated to ICT and not the health information system, as noted by a CMED Director: “…staff allocated are mostly focused on keeping the ICT equipment running, process salaries and do not deal with health information system issues.” In order to mitigate this challenge, a strategic relationship was formulated with HISP UiO through the University of Malawi. This brought on board three constituent colleges of the University of Malawi: College of Medicine, Malawi Polytechnic and Chancellor College. At that time, the ICT infrastructure at the College of Medicine was amongst the best in the Malawi with a stable and reliable Internet connection, while Malawi Polytechnic and Chancellor College had ICT staff which could be leveraged. In addition, a local organization called HISP Malawi was established to provide the required technical support for the implementation and management of DHIS2. To manage HISP Malawi, a five-member board was constituted, drawing its members from MOH/CMED and the three mentioned colleges at the University of Malawi. Second, as a web-based system, DHIS2 required a stable hosting space with adequate bandwidth to handle the data traffic from various users. However, the Government Wide Area Network (GWAN) through which MoH gets internet connectivity is known for being unstable; often up but also down and when up, the quality of the connection is often poor. Furthermore, “GWAN is very slow … we found its infrastructure inadequate and unstable to run DHIS2” (Chief Technical Assistant, CMED). Therefore, alternative means of hosting DHIS2 were required. There were three options on the table: (1) setting up a DHIS2 web server at CMED with its own dedicated Internet connection, (2) using a web hosting service outside Malawi and (3) hosting DHIS2 with a partner institution in Malawi. Setting up a web server for DHIS2 at CMED and acquiring dedicated Internet connection proved to be a costly endeavor. At the same time, the MoH was not in favor of hosting health data outside Malawi. Because College of Medicine had the best ICT infrastructure and good Internet connectivity, a decision was made to host DHIS2 at the College of Medicine. Third, with other higher priority health areas to finance, there is usually little left to finance health information systems initiatives. Not surprisingly, the ministry did not have funds for the DHIS2 pilot project and alternative sources of funding had to be explored. Fortunately, the University of Oslo provided the funds for a pilot project. With funds available, two fresh graduates from the University of Malawi were recruited under HISP Malawi and placed on secondment to CMED as technical assistants on the project. The pilot project ran from 2009 to 2012 and DHIS2 was rolled out countrywide in 2012 with support from various stakeholders including: Norwegian Agency for Development (Norad), Support for Service Delivery Integration (SSDI), United Nations Children’s Fund (UNICEF), Centre for Disease Control and Prevention (CDC), International Training and Education Centre for Health (I-TECH), HISP Malawi and the University of Oslo (Department of Informatics).

4.2. Emerging needs for innovation

The national rollout of DHIS2 implies that data are now transmitted electronically from the district level to the national level. However, from the health facility level to the district
level, data reporting is still paper-based. This is because most health facilities do not have electricity, Internet connectivity and/or computers. Data at the health facility level are collected through a paper-based system of registers and aggregated monthly on paper forms. The forms are then sent on paper to the district level where the aggregate data are entered into DHIS2. Aggregate data are therefore entered twice: first onto the paper forms at the health facility level and then into DHIS2 at the district level. As noted by the Chief Statistician at CMED: “This is a challenge; it makes data reporting slow and tedious.” This is one example of how DHIS2 has brought forward local demands for further innovations in order to support its local use. In the subsections below, we describe three different local innovation initiatives being undertaken in Malawi.

4.3. Integration

The health system in Malawi has a history of fragmentation and reporting systems that make access and sharing of data among various geographically distributed stakeholders difficult. There are human resources management, logistics and medical record information systems producing data that in aggregated form is to be entered into DHIS2. The data from these systems are manually aggregated and then entered into DHIS2. To reduce the efforts required for data reporting, there is a call for integration between DHIS2 and auxiliary systems to enable information flow electronically between the systems.

Responding to this call, in the last quarter of 2015, MoH recruited a technical assistant through HISP Malawi to work in close collaboration with other stakeholders on integrating their systems with DHIS2. One such stakeholder is Baobab Health Trust. Baobab Health Trust is a local NGO that develops and maintains a suite of touchscreen-based electronic medical record (EMR) systems used by health facilities across Malawi. The Baobab EMR suite includes applications for patient registration, in- and out-patient diagnosis, maternal care, antiretroviral therapy, pharmacy inventory control and billing as summarized in the Table 3.

The Baobab EMR suite is used in more than 60 health facilities across Malawi and there are plans to introduce it to more health facilities. Baobab Health Trust is also working together with the National Registration Bureau and the MoH on an electronic birth registration (EBR) system which will allow babies to be registered at birth. Currently, the EBR system is being piloted in four hospitals across the country. In health facilities where

| Table 3. System components composing the EMR suite offered by Baobab Health Trust. |
|--------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| **System applications**               | **Description**                                                                                                                                                                                 |
| Patient registration                  | Registers every patient and issues a unique ID in form of a barcode pasted on a patient’s health passport. The barcode allows continuity of care where once scanned previously recorded patient’s information is retrieved |
| In- and out-patient diagnosis         | Linked with the patient registration module, allows clinics to record both primary and secondary diagnoses                                                                                         |
| Maternity                            | Registers, admits, diagnoses, discharges and refers pregnant women from antenatal ward or labor ward to post-natal ward                                                                         |
| Baobab antiretroviral therapy (BART) system |                                                                                                                                                                                                  |
| Pharmaceutical inventory control      | For the management of pharmaceutical items                                                                                                                                                      |
| Billing                              | For the management of paid health services                                                                                                                                                       |
the Baobab EMR and EBR systems are running, data are first electronically captured into the systems, and later manually aggregated for entry into DHIS2. Integrating Baobab systems with DHIS2 will potentially reduce the time and effort required to collect and aggregate data for entry into DHIS2. But getting appropriate access rights to DHIS2 from HISP Malawi has challenged Baobab’s attempt to integrate: “We had one of our software developers working on integrating our EMR with DHIS2 but we were unable to secure appropriate access rights to DHIS2 from HISP Malawi to allow us test our solution” (Director, Baobab Health Trust). Even technical assistants working under CMED have experienced this: “At one time one could be granted super-user rights to DHIS2, only to realise later that those rights have been revoked without us being informed” (DHIS2 Technical Assistant, CMED). There are limits to what MoH and other stakeholders can do with respect to DHIS2. Control and ownership over DHIS2, shared between CMED/MOH and HISP Malawi, were by other actors found to be confusing. To improve this situation, a project was carried out to introduce a mirror server for DHIS2 at the MoH to run parallel with the one at College of Medicine. MoH with support from various stakeholders established a server room equipped with good Internet connectivity at the offices of its Community Health Services Unit (CHSU). The server room is hosting other information systems such as the Human Resources Management system and Logistics Management system. It is expected that once the mirroring is done, the DHIS2 server at CHSU will be the main server with the server at College of Medicine acting as a backup. This will give MoH and other stakeholders more leeway and the requisite flexibility to implement desired innovations. Furthermore, a memorandum of understanding between MoH and HISP Malawi is being drafted which when signed will formalize the relationship and add transparency to matters of control, ownership and accessibility.

4.4. Reconfiguring DHIS2

When a decision was reached to mirror the DHIS2 server at College of Medicine with a new server at CHSU, it was also observed that the current configuration of DHIS2 has some shortfalls that needed to be ironed out. For example, there are cases of data duplication whereby similar data are entered in different datasets in DHIS2 by two or more health programs. Furthermore, the way the majority of data elements are currently configured prevents certain high-level data analysis and reporting required by various health programs and stakeholders:

Instead of just mirroring the two servers and inherit the challenges we are facing with the current configuration it is better that the new server be reconfigured in such a way that we can migrate all data from the old server but also get rid of its shortfalls. (Senior Technical Advisor, Health Information Systems Strengthening Programme, MoH)

A decision was therefore made to embark on a DHIS2 reconfiguration instead of mere mirroring of the DHIS2 servers at College of Medicine and the CHSU. Mirroring became one of the several objectives within the DHIS2 Reconfiguration project described below.

4.4.1. Aligning together stakeholders for DHIS2 reconfiguration

DHIS2 in Malawi involves several local and international stakeholders in terms of its use as well as development. Thus, the DHIS2 Reconfiguration project attracted interest from
several stakeholders working together by drawing upon their resources, experiences and expertise. This includes people from CMED/HISP Malawi, MoH ICT Department, MoH Programme Coordinators, Baobab Health Trust, GIZ/EPOS Health Management and the University of Malawi, Chancellor College. In addition, the DHIS2 Reconfiguration was supported by the University of Oslo, the Global Fund and UNICEF.

To effectively work together, there was a need for proper alignment of the stakeholders involved. First, it was important to ensure that the DHIS2 reconfiguration implementation team had proper access rights to DHIS2 at the College of Medicine. Following a series of meetings, administrative rights over the server was established and DHIS2 super-user accounts were made available to CMED. Furthermore, standard working procedures were drafted to guide the collaboration between the stakeholders by defining permission and control structures. Consultations were made with the head of the ICT department in the MoH which lead to allocation of two members of staff to work with CMED on DHIS2. A larger implementation team was further established comprising nine technical staff drawn from different stakeholders: two members from CMED/HISP, two members from MoH ICT department, two members from Baobab Health Trust, two members from University of Malawi and one member from EPOS Health Management. The implementation team was supported by a two-member administrative team: one member for CMED and one member from EPOS Health Management.

4.4.2. Capacity building and DHIS2 reconfiguration

In order to build the required capacity to reconfigure DHIS2, the implementation team took part in training activities. First, a DHIS2 Application Development workshop took place at the University of Malawi, Chancellor College from 7 March to 16 March 2016 (University of Malawi, 2016). The training introduced participants to the current DHIS2 configuration, the DHIS2 API and how to develop DHIS2 applications using them. The training was funded by the University of Oslo with support from UNICEF. It attracted participants not only from Malawi but also from Kenya, Ethiopia, Zambia and Malawi. Five of the members of the implementation team attended the training. A second training was carried from 21 March to 2 April 2016, prior to the start of the DHIS2 reconfiguration. The second training was funded by the University of Oslo with support from Global Fund. It was facilitated by a consultant and expert on DHIS2 from the University of Dar es Salaam, Tanzania. This training introduced participants to DHIS2 installation on the Linux operating system, how to configure DHIS2, and how to backup and restore DHIS2 instances. Only five members of the implementation team managed to attend both rounds of training. As a result, from 4 April to 8 April, a follow-up training was organized to bring the other four members up to speed. This was facilitated by the five members who attended the earlier training.

Effectively, the reconfiguration commenced on 11 April 2016 with the installation of a DHIS2 instance on the CMED server at CHSU. This was followed by the redefinition of data elements in order to get rid of the anomalies associated with the DHIS2 instance at College of Medicine. Programme Coordinators were consulted to provide clarification of data elements related to their programs. Where data duplication across programs was identified, respective coordinators were called to a joint meeting to agree which program would be responsible for collecting the data in question. For example, both the TB program and the HIV/AIDS program were found to be collecting TB-HIV coinfection
data in their datasets. Following consultation, it was agreed that the TB program will collect this particular data and the HIV/AIDS program will reuse this data for its own purposes. Decisions like these led to the redefinition of program datasets and subsequently their reconfiguration in the DHIS2 instance at CHSU. The implication of this is that although the DHIS2 instance at CHSU is meant to capture the same data as the one at College of Medicine, in terms of data elements and dataset configuration, the two instances are significantly different. Thus, the data in the DHIS2 instance at College of Medicine had to be migrated to be aligned with the new configuration used in the CHSU instance.

Data migration between the two DHIS2 different instances required mapping data elements from the College of Medicine instance to corresponding data elements in the CHSU instance. This involved extracting three IDs for each data element (a total of six IDs for both instances) and browsing three pages of the DHIS2 Web API (a total of six for both instances). Most datasets have hundreds of data elements. Therefore, manually mapping data elements was going to be tedious and slow, making the DHIS2 reconfiguration unattainable within the project timeframe. To speed up the process, applications to automate the data migration were required. Drawing from the DHIS API knowledge acquired during the trainings, the implementation team developed a set of applications. The first application is called Dataset Details Lister. This is a DHIS2 web application that lists data elements and their corresponding IDs for a selected dataset. This information is then taken to a spreadsheet to create a dataset map between two corresponding datasets of the two DHIS2 instances. The second application is called Data Migrator. This is a PHP application that uses the DHIS2 API to connect to both DHIS2 instances and uses the dataset map created from the output of Dataset Details Lister to migrate data from the instance at College of Medicine to the one at CHSU. The third and last application is called Data Migration Validator. This is a PHP application that uses the DHIS2 API to connect to both DHIS2 instances and checks if the data migrated across the instances are matching and flags out any mismatches. Mismatches can happen as a result of errors in mapping data elements or problems with the Internet connection. To speed up correction of such mismatches, the application was further improved to automatically fix any mismatches identified. This is only done if the mapping process is confirmed to be free of errors. Together, these three applications enabled a fast-tracked data migration process. Figure 1 illustrates the relationship between the three applications and the two DHIS2 instances.

The DHIS2 reconfiguration project employed a phased agile approach where different health programs were reconfigured and migrated in different time boxes according to priorities assigned to each program. The project was scheduled to run up to August 2017 with the first set of reconfigured and migrated programs delivered in June 2016. At this point, it was expected that those programs will make a switch from the DHIS2 instance at College of Medicine to the DHIS2 instance at CHSU. However, a challenge emerged with respect to limited Internet bandwidth at CHSU which led to the switch being delayed. The limited bandwidth is the result of the server room hosting several other web-based health information systems in addition to the new DHIS2 instance. The Internet connection is also used by members of staff of the HIV/AIDS department for various office duties. Switching the reconfigured programs to the DHIS2 instance at CHSU without upgrading the bandwidth will result in poor response time. The matter was tabled at a
stakeholders meeting and a cost-sharing agreement was made toward upgrading the available bandwidth. Although the project was initially scheduled to run up until August 2017, the automation of migration through the three applications mentioned above allowed the migration to be completed four months ahead of schedule. As a result, there was a switch to the new instance in April 2017 instead of August 2017.

4.5. The League Table App

Another initiative extending the DHIS2 in Malawi is the League Table App. Feedback practices such as review meetings at health districts have been taking place at all levels for a long time in Malawi (Moyo, Frøyen, Sæbø, & Kaasbøll, 2015; Moyo, Kaasbøll, Nielsen, & Sæbø, 2016). The review meetings bring together various stakeholders such as District Managers and NGOs, to examine performance data, provide feedback and develop action plans to improve the data. Feedback is also provided to health facilities during supervision by teams from the district. Districts produce and disseminate HMIS annual bulletins, as a means of providing feedback. To strengthen the HMISs, the MoH in collaboration with the University of Oslo has piloted and tested several different versions of league tables in different districts. League tables are used to compare the performance of different entities at the same level of the health systems by ranking them.

As an internal decision support tool, the league table can be developed and used by the district health management teams themselves. The league tables can also be presented in the district HMIS bulletins so that they are available for a wider group of users. The design of a DHIS2 League Table App was undertaken by two Master students at the University of Oslo as part of the course and project work (see Figure 2 for an example user interface).
The design started in January 2015 and it culminated into the piloting of the solution in Malawi in November 2015. This combination of members with different backgrounds, interests, roles and responsibilities enriched the interactions and consultations between the developers of the app, researchers and the head of the CMED at the MoH responsible for data management and DHIS2 in Malawi (who was part of the research team).

A series of meetings were held at the University of Oslo among the researchers to plan the pilot. The identification of the indicators was based on programs with high reporting rates in DHIS2. Based on this, the League Table App used indicators, as a starting point, from the following reports: HMIS15 summary report, Family Planning, Antenatal care, Maternity and Malaria program reports. The league table was designed as a separate app using the DHIS2 Web API to access the data from DHIS2. It offers the health managers the flexibility to define their own league tables based on the indicators they find relevant and they can give the different indicators different weights in the total ranking. Currently, there is a project funded by UNICEF aimed at integrating the League Table App with another DHIS2 data visualization app, the Scorecard App. The new app will be piloted in Malawi, Uganda and Tanzania in 2017. The new app is being developed by developers from HISP Tanzania and University of Malawi.

In Table 4, the key DHIS2-related activities in Malawi in the period 1999–2016 are summarized.

5. DHIS2 and socio-technical generativity in Malawi

In this section, we link the case study to our proposed perspective on socio-technical generativity. We do so by first illustrating how the technical attributes of DHIS2 influenced...
innovation in Malawi, then how social attributes played a role, and finally, how these social and technical attributes were interrelated in the way they influenced innovation. By doing so, we show the strength of our holistic perspective on socio-technical generativity and how it supports the recognition of the complementarity between social and the technical factors in the way they influence innovation.

5.1. The technical attributes of DHIS2 and generativity in Malawi

In Section 3, we introduced five attributes of technology influencing generativity: capacity for leverage, adaptability, ease of mastery, accessibility and transferability. In this section, we discuss each of these attributes related to DHIS2 in Malawi. First, DHIS2 with its data management, visualization and web-based futures offered the Malawian Ministry of Health and CMED a tool they could leverage to reduce the fragmentation of the multiple existing information systems. This improved the ease of access to information across health programs and improved data quality. Second, the adaptability of DHIS2 is, for example, reflected in the three applications developed using the Web API to facilitate data migration from the old to the new DHIS2 instance and the piloting of the league table. Third, with respect to ease of mastery, DHIS2 offers a mature, well-proven and well-structured Web API and it comes with extensive online documentation.

The documentation provides users, implementers and third-party application developers the means to learn and master various aspects of the platform and the API. While the documentation was a key source of information for the implementation team, it was also observed that the documentation sometimes is vague and out of sync with the different versions of DHIS2. The amount of effort required to adapt DHIS2 can be discussed on three different levels in the case of Malawi. First, the team had the required skills to configure DHIS2 to fit the particular requirements. Second, they also had the skills needed to reconfigure DHIS2 and develop the League Table App by using the DHIS2 API. Third, even if DHIS2 is open-source software and anyone can easily inspect the code and make changes to the core, this did not happen in Malawi. There can be many reasons for this, including the lack of expertise needed to understand the core code, uncertainty about the consequences of changing it and the risks of making software that may end up incompatible with future versions of DHIS2. Fourth, DHIS2 is open source and free of charge to download and use. Without expensive licenses as an accessibility barrier, DHIS2 was highly attractive for Malawi as a developing country and with its very limited resources for investments in software. Fifth, DHIS2 is highly configurable and customizable, and has an extensive API allowing for integration with other systems. The strategy behind DHIS2 is based on supporting diverse needs from diverse use contexts.

Table 4. Key DHIS2-related activities in Malawi.

<table>
<thead>
<tr>
<th>Time period</th>
<th>Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>1999</td>
<td>HMIS Strengthening Programme Starts</td>
</tr>
<tr>
<td>1999–2002</td>
<td>HMIS Review, establishing a picture of a fragmented HMIS and the need for consolidation</td>
</tr>
<tr>
<td>2002–2008</td>
<td>DHIS introduced and implemented</td>
</tr>
<tr>
<td>2009–2014</td>
<td>DHIS2 introduced and piloted</td>
</tr>
</tbody>
</table>
| 2015–2017   | - MOU and technical working procedures to facilitate collaboration and integration  
              - DHIS2 reconfiguration  
              - DHIS2 trainings  
              - League Table App piloting |
in different developing countries. Based on an approach of “open generification” (Gizaw, Bygstad, & Nielsen, 2017), DHIS2 can be transferred to, customized and implemented in most contexts and it is up to the user to configure it related to, for example, organizational hierarchies, health indicators, language and dashboards. To support the sharing of innovations made on top of DHIS2 across organizations and countries, HISP UiO has also established a DHIS2 App store. In Malawi, this enabled the implementers to configure DHIS2 to fit the context and share local innovations globally.

DHIS2 shows the attributes of a generative technology in Malawi. Compared to the earlier desktop version, it offered the required leverage (web-based), it came without the classical accessibility barriers in developing countries (no proprietary software and associated license costs) and it offered the adaptability to customize it for local needs and introduce new innovations on top of it.

5.2. Generative relationships and DHIS2 in Malawi

In Section 3, we also introduced five attributes of social relationships influencing the generativity of a technology: Aligned directedness, heterogeneity, mutual directedness, appropriate permissions and action opportunities. In this section, we discuss each of these attributes related to DHIS2 in Malawi.

First, the implementation of DHIS2 brought together people from different organizations and domains: The CMED from the Ministry of Health, researchers and technical experts from the University of Malawi and the University of Oslo, and other local and international organizations. They were all working in the same direction and toward strengthening the national HMIS in Malawi. Second, this heterogeneous group of organizations and people had different competences, social positions and access to resources. These resources were in many ways complementary. For example, the CMED possesses domain expertise but lacks the required software and hosting capacity needed to implement and use DHIS2. The College of Medicine had the infrastructure necessary to host DHIS2 and HISP Malawi and HISP UiO contributed with their capacity to implement and customize the software. Third, HISP Malawi played a key role in bringing these different actors together. HISP Malawi was established based on members from different local stakeholders. Some of the members were also graduated with PhDs from the University of Oslo. Through their education, they were exposed to and became a part of the “ideology” of HISP UiO, namely the Networks of Actions approach (Braa & Nielsen, 2015). At the core of this “ideology” lies the idea that action research-based interventions in developing countries must be part of larger networks to be sustainable. Sustainability and success are an outcome of collective actions by a network of engaged organizations and individuals locally and globally. This acted as a platform for HISP Malawi where differences and complementarities were appreciated, despite the diversity of the organizations involved. Fourth, the core of the network of action is the action research supporting the implementation and further development of DHIS2. Experiments, prototyping, student projects and innovation to meet user needs compose the modus operandi of this global network. During the process of implementing DHIS2, CMED also permitted the hosting of DHIS2 at the college of medicine instead of using the GWAN infrastructure. Hurdles to innovation, like the limitation of access to integrate new solutions to DHIS2, were effectively remedied with a memorandum of understanding between MoH and HISP Malawi and the
introduction of standard working procedures. As a part of this, researchers and students from the University of Oslo got the appropriate permissions from CMED to engage with their expertise and learn from the concrete cases in Malawi. Fifth, the network of actors involved locally and globally created an environment where new attributions could emerge. This environment was conductive for innovation on several levels. First, domain experts, implementation experts and DHIS2 software experts were working together on the ground in Malawi. At the same time, this team was linked to the global network of HISP experts through personal networks and online DHIS2 forums where there is an ongoing discussion of opportunities and issues. Second, regional DHIS2 academies and workshops are arranged annually with the aim of building capacity as well as facilitating peer-to-peer sharing of experiences and ideas among different experts in the network. Third, the involved students from the University of Malawi and the University of Oslo all had a strong drive toward experimenting with and improving DHIS2 to meet emerging user needs.

In Malawi, DHIS2 is supported by generative social relationships. These relationships are composed of a strong local network of heterogeneous partners linked to a global network of DHIS2 experts. The driving force in these networks is innovation to strengthen HMISs in developing countries.

5.3. Socio-technical generativity and DHIS2 in Malawi

From the analysis above, we argue that DHIS2 and its related social relationships in our case in Malawi are generative. Through the analysis, we have also shown that it does not make sense to look at technological or social factors in separation. Generativity is socio-technical. An illustrative example of this is the DHIS2 reconfiguration and the development of the apps required (Dataset Details Lister, Data Migrator and Data Validator). While DHIS2 offered the necessary Web API, it would have been useless without the adequate administrative server rights to DHIS2 at College of Medicine, the expertise knowledge required to map the data in the different databases as well as the expertise to develop apps outside for efficient mapping, and at the same time using the DHIS2 API. And vice versa, without the required Web API, the network of experts would not have achieved much. Such a situation is well illustrated with the previous DHIS based on proprietary technology, hampering local customization and not allowing for extension of its features and thereby mandating the end users to use it as it was. The implication of this was that stakeholders had no other option but to create new systems – exactly what the project set out to avoid in the first place. A similar challenge was met by Baobab when HISP Malawi did not grant them access to DHIS2 and integrate their EMRs system with it. Based on the existing social relationships, this hurdle was quickly removed.

5.4. Socio-technical generativity in the fringes

With its platform design, DHIS2 does not only depend on the core team of developers at the University of Oslo, but also a network of local experts. Software platforms are “half products” which have to be configured, customized and extended to meet the needs of a specific context (Dittrich, 2014). And the continuous geographical expansion of the
platform has fueled its generic as well as generative nature by introducing new use contexts, use cases and application domains (Nielsen & Sæbø, 2016). As a developing country, Malawi has limited resources to invest in and human capacity to engage in software development. And as a relatively small country located geographically far away from the University of Oslo, it is in many ways at the fringes of the DHIS2 software ecosystem. From a technical point of view, the platform nature of DHIS2 makes space less a concern as long as DHIS2 offers the needed technical support for local innovation. The possibility for a stakeholder in Malawi to make the team in Oslo change the core software is at the same time limited (Gizaw et al., 2017).

While software can travel fast and freely globally and to the fringes of software ecosystem, establishing the required local capacity and social relationships is much more challenging. In the case of DHIS2 in Malawi, this included establishing access to servers, building the capacity to customize, implement and use DHIS2, and establishing and nurturing the necessary relationships to innovate on top of it. These relationships were local, but also global and linking the local initiatives with the region and the global HISP network through, for example, DHIS2 academies.

5.5. Socio-technical generativity and time

While social and technical attributes of generativity are necessary to support innovation, they develop independently and not necessarily in sync. The establishment of generative relationships does not necessarily coincide with the presence of generative technologies, and vice versa. For example, the local capacity in Malawi to implement, use and maintain DHIS2 has developed and matured slowly since the HMIS strengthening program was started in 1999. A key element in this was from the beginning the HISP project and the PhD program at the University of Oslo were Malawian students were enrolled and later graduated. While this capacity was building up, the previous version of DHIS and its proprietary technology basis continued to offer only limited technological capacities for innovation. This continued until the new DHIS2 was launched in Malawi in 2009. And the technical capacity of DHIS2 to support innovation did not fully come with its first release, but developed over time as DHIS2 matured as a platform with improved documentation and a maturing Web API. Turning DHIS2 into a platform was a strategic move by HISP UiO to meet a rapidly expanding demand for flexibility to meet new requirements from numerous new countries implementing the platform. To support this, HISP UiO actively worked toward establishing a global network of DHIS2 experts and software developers to develop apps. Still, the DHIS2 experts are primarily engaged in customizing and implementing the software while the software team at the University of Oslo is doing the vast majority of the software development. The relationship between social relationships, technological capacities and time is summarized in Table 5.

6. Implications for research and practice

The aim of this paper is to build and discuss a holistic account of the technological and social factors constraining and enabling innovation in the fringes of software ecosystems. The main contribution of this paper, the concept of socio-technical generativity, is
developed and discussed related to activities of innovation around the software platform DHIS2 in the developing country context of Malawi.

*Socio-technical generativity* acknowledges the complementary roles of social relationships and the capacity of technology in the shaping of innovation processes. As demonstrated by the case in Malawi, even if a technology is generative, it makes little difference in the fringes of a software ecosystem without the required social relationships to develop and nurture novel attributions. At the same time, the existence of strong social relationships in the fringes and relationships linking the fringes to regional and global networks is not enough to enable innovation if the attributes of the technology are not supportive of innovation. We have also shown how these different attributes change, and not necessarily in sync, and relate both to space and time.

Platforms have a central role in the increasing focus on digital innovation in society in general, and information system research in particular. With the significant prospect of digital innovation as argued by the trade and popular media, this research will potentially have significant impact. As a part of information systems research already engaged in the study of software platforms and innovation are calls to focus more on strategic roles of business frameworks (Yoo et al., 2010) and innovation networks (Lyytinen, Yoo, & Boland Jr., 2016). Nielsen further argues that also ICT4D research must engage in the role of software platforms in developing countries and how developing countries can actively contribute to and not only act as users of digital innovations (Nielsen, 2017). Innovation as a human activity includes access to and the understanding of the inner workings of technologies as well as the opportunities to develop new attributions of technology and act on them.

We have developed our concept of *socio-technical generativity* in the context of an open-source software platform and the network around it working toward strengthening the health system in developing countries. We argue that our perspective on socio-technical generativity will yield useful insights also in the analysis of other software platforms and bring understanding to how they are related to innovation. With a strategy of

<table>
<thead>
<tr>
<th>Time periods</th>
<th>Social relationships</th>
<th>Technological capacity</th>
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<tbody>
<tr>
<td>1999–2002</td>
<td>- Building a shared understanding in Malawi regarding the weaknesses, and in particular the fragmentation of the HMIS</td>
<td>- DHIS with limited accessibility due to license costs not matching budgets - No flexibility to change with the result of different stakeholders investing in different systems</td>
</tr>
<tr>
<td>2003–2008</td>
<td>- The capacity to use DHIS slowly building up in Malawi through PhD program - Malawian PhD students building links nationally, regionally and globally</td>
<td>Status quo</td>
</tr>
<tr>
<td>2009–2017</td>
<td>- Capacity to use and participate in the development of DHIS2 building slowly up in Malawi - HISP Malawi established, drawing together expertise from different domains - A global network of DHIS2 experts established with key people from HISP Malawi</td>
<td>- DHIS2 established as open-source and web-based software - A maturing Web API with extensive functionality and documentation - DHIS2 Academies established - DHIS2 App development workshops creating/enhancing local capacity to develop DHIS2 apps - DHIS2 App store enabling transferability of innovations within the ecosystem</td>
</tr>
</tbody>
</table>
supporting the implementation and use of DHIS2 as a global public good, HISP UiO is not designing an open technology platform with the aim of generating revenues. Rather, the design is geared toward strengthening national health information systems, fostering local innovation and the creation of local business in developing countries and regional collaboration. DHIS2 may have very different attributes and develop differently compared to other software platforms. For example, commercial platforms will require different business cases and typically have a much shorter time horizon to recoup investments. Thus, it remains to be seen if our perspective on generativity also makes sense related to other software platforms and other contexts.

From a practical point of view, our case study of DHIS2 in Malawi and our perspective on social-technical generativity have implications for both the design and implementation of software platforms in developing countries. First, software platforms must be designed and implemented with the necessary attributes of technology and social relationships. As a starting point, the platform must offer the required accessibility, adaptability and ease of mastery in the context it will be used. This will require developers to engage with and understand what the users need to participate in innovation, facilitate local capacity building and the development and distribution of the necessary tools, teaching materials, documentation, etc. In developing countries where resources are scarce, this is demanding. Engaging local higher education institutions to participate in and drive these processes has shown highly successful and sustainable in the case of DHIS2. Second, and as a natural part of capacity building, participants will build social relationships locally. Platform developers should nurture these relationships as well as work toward the establishment of regional and global networks of experts. These networks should not be limited to a certain group professionals, but should be heterogeneous and always include experts on technology as well as from relevant application domains. These relationships are not built overnight and careful planning is needed to ensure the resources and incentives necessary to sustain them over time. The value of creating local business opportunities and career paths for experts is a key learning from DHIS2 in this respect. Third, it is crucial to assure the openness of platforms in terms of offering appropriate permissions to a wide audience to innovate on top of it. This may simply be a matter of offering access rights easily and widely, or in other cases, long-term engagement in advocating for, making and implementing policies to establish a regime of openness.

We have in this paper developed a socio-technical perspective on generativity based on studying a software platform in a developing country. While we have illustrated the usefulness of this perspective in Malawi and related to DHIS2, it requires further research to show its value in other contexts and related to other software platforms. It would also be interesting to further explore the analytical strength of our perspective by also studying in a more focused way the role of platform “owners” (HISP UiO in our case). We have also focused on developing a holistic perspective by bringing two separate perspectives on the social and the technical together. In this, we have paid limited attention to the particular attributes of these perspectives. Further research is needed to scrutinize these attributes as a part of a holistic perspective and possibly remove, reframe or add new attributes. There is also a need to more in depth explore the relationships between the different social and technical attributes and the potential positive and negative influence between them and how they may reinforce or counteract each other. Finally, we have focused on the context of DHIS2 and how it has developed in Malawi from 1999 to 2017. But this is an ongoing
process and the way in which DHIS2 as a platform continues to develop in Malawi should be followed further.

**Disclosure statement**

No potential conflict of interest was reported by the authors.

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