

Final Report Executive Summary



HSC R&D Division Final Progress Report

Final Reports should be submitted via electronic copy to HSC R&D Division within 6 weeks of the request. The report should be completed on the attached form in clear typescript. Please extend boxes as required. Please adhere to any word limits. These reports may be subject to external peer review. Details from the Final Report may be placed on the HSC R&D Division website and shared with appropriate key stakeholders or members of the public.

HSC R&D Division Award Details

HSC R&D File Reference	COM/5432/18
HSC R&D Funding Scheme	Opportunity Led
Project Title	Development of a Connected Health Living Laboratory
Award Holder Name (Employer)	Chris Nugent
Host Research Organisation	Ulster University
Award Duration	2 years
Award Start Date	01/08/2018
Award End Date	31/07/2021
Name of Lead Supervisor: <i>(only applicable to training awards)</i>	

Signature

Award Holder Signature:	
	Date: 17/09/21

Evidence Brief

(1 page: which may be used for dissemination by HSC R&D Division)

Why did we start?

(The need for the research and/or Why the work was commissioned)

Healthcare is increasingly challenged to meet the demands of user involvement and the knowledge mobilisation required for modern patient-centred care and knowledge-based economies. Innovations, such as the Living Lab concept, are required to reduce problematic barriers to knowledge exchange and to improve collaborative problem solving. Living labs, as open knowledge systems, have the potential to address these gaps, however, are to date underexplored in healthcare. This project aimed to provide a unique environment to support multi-disciplinary research in the area of connected health through establishment of Ulster's first Connected Health Living Lab.

What did we do?

(Methods)

The Project created a dedicated environment to support user and clinical engagement in the development and evaluation of connected health solutions. Within the environment users of the lab were able to access to state-of-the-art resources to assess usability and interactivity with innovative connected health solutions. This facilitated a dedicated environment to observe naturalistic user behaviours with new connected health solutions.

We engaged with 13 Projects and 180 stakeholders and assisted with the development and evaluation of a range of connected health solutions.

What answer did we get?

(Findings)

As a potentially untapped resource to support the development of Connected Health solutions, it was found that the Living Lab methodology offered benefits at all stages of the development cycle to all stakeholders involved

What should be done now?

(Practice/Policy Implications and/or Recommendations)

The Project has 4 recommendations:

1. The Living Lab as a methodology has benefits in the design and evaluation of Connected Health solutions and as such should be further exploited within the research area.
2. The resource created can be exploited by any further Connected Health Projects to avoid duplication of efforts.
3. Both the physical and operational space should be reconfigurable and not fixed by nature.
4. To maximise uptake sharing of best practices and standardization of approaches is necessary.

Final Report

(no more than 20 pages)

Please structure the report using the headings below

Background

Digital Health solutions, and in particular Smartphone apps, are already changing the way people interact with healthcare. Their potential to transform various aspects of care delivery, shifting from crisis intervention towards prevention, enablement and supported self-management has been highlighted in numerous reports. Most notably these include the Health and Wellbeing 2026 – Delivering Together launched in October 2016 by the Department of Health and The Topol Review - Preparing the healthcare workforce to deliver the digital future, February 2019.

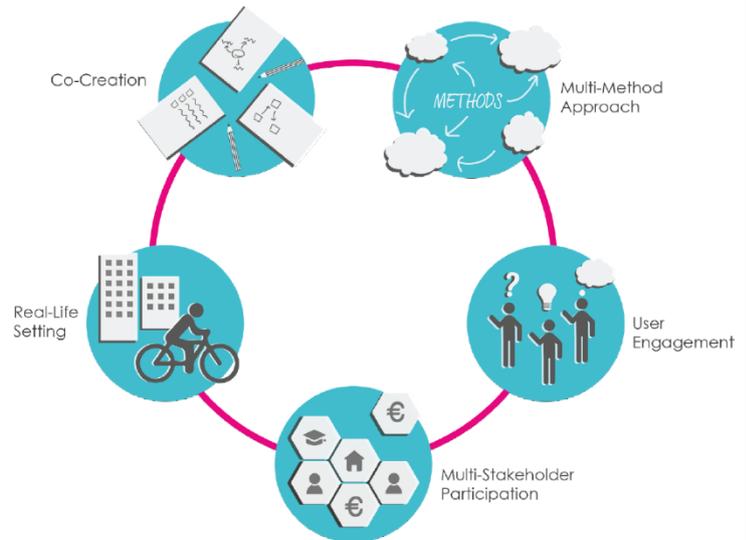
These two reports highlight that in order for these technologies to meet their potential, we need to work with patients and healthcare providers to co-create applications of digital technologies which meet their needs. Healthcare is increasingly challenged to meet the demands of user involvement and the knowledge mobilisation required for modern patient-centred care and knowledge-based economies. Innovations, such as the Living Lab concept, are needed to reduce problematic barriers to knowledge exchange and to improve collaborative problem solving. Living labs, as open knowledge systems, have the potential to address these gaps, however, are to date underexplored in healthcare.

This project aimed to establish Northern Ireland's first Connected Health Living Lab (CH:LL) within the School of Computing at Ulster University in partnership with the School of Nursing and the School of Engineering. CH:LL leverages research expertise in the creation, development and evaluation of cutting-edge technologies. This includes vast experience in usability and human computer interaction. This expertise is combined with state-of-the-art facilities in usability assessment, vital signs, mobile and wearable computing and virtual and augmented reality.

Aims and objectives

This project aimed to provide a unique environment to support multi-disciplinary research in the area of connected health- The CH:LL. The lab provides the following opportunities:

- A dedicated environment to support user and clinical engagement in the development and evaluation of connected health solutions.
- Access to state-of-the-art resources to assess usability and interactivity with innovative connected health solutions.
- An opportunity to establish the processes governed by MHRA and GDPR regulations in software development for connected health solutions.
- A dedicated environment to observe naturalistic user behaviours with new connected health solutions.
- An appealing space to facilitate Public Engagement and PPI related events.



The Living lab provides infrastructure to facilitate a user-centered, open innovation ecosystem, integrating research and innovation within a Public-Private-People partnership delivered through an iterative experiential design process. This provides a unique opportunity to engage in multidisciplinary and intersectoral co-creation thus strengthening civic engagement and the opportunities for creating innovative solutions. CH:LL aligns with the University's Five Year Strategic Plan, Five & Fifty (2016), with potential to contribute significantly to the University's civic contribution and to undertaking high quality research with impact.

The creation of the living lab also aligns well with the approach outlined in Northern Ireland's HSC R&D Strategy 'Health and Wellbeing 2026 – Delivering Together'. This report highlights partnership working and eHealth as main pillars to this strategy. The living lab facilitates the development of Connected Health solutions, an area which has been identified as a smart specialization priority for substantial growth and investment within the Northern Ireland Innovation Strategy.

To deliver on the aim, the project had the following objectives:

1. Creation of Connected Health Living Lab by 31 March 2018
2. Develop Training Facility and improve skill base of Ulster University staff to use Connected Health Living Lab, as evidenced through a pre and post skill assessment questionnaire measuring the Likert scale of responses in confidence, knowledge and ability of use of Living Labs, by 31st March 2019.
3. To increase the number of funding applications to RCUK from 0 per year to 2 per year by the end of year 3
4. To increase the numbers of 3* and 4* research publications per year which have used the Living lab concept, from zero at present to 2,3,4,5 over a period of 5 years (14 in total over a period of 5 years).
5. To increase the numbers of cross discipline internal collaborative Projects which make use of the Living Lab from 0 at present to 1 per year by the end of year 3 (March 2021).
6. To secure £100k funding per annum, by the end of year 2 (March 2020) to ensure the self-financing of the 2-research staff to support the operations within the Living Lab.

Methods

The establishment of the living lab has required completion of a number of strategic tasks. These are related to establishing the environment, upskilling of staff to utilise the equipment, ethics and user engagement and sustainability and new partnerships. A summary of the tasks can be found below. Further details can be found in the accompanying document.

- 1.1 Finalise lab environment
- 1.2 Development of publicity material
- 1.3 Public Opening of Lab
- 2.1 Develop training materials
- 2.2 Run suite of training seminars
- 3.1 Engagement with currently funded Projects
- 3.3 Development of funding proposals
- 4.1 Connected Health living lab ethics
- 4.2 Ethical Applications
- 4.3 Recruitment and stakeholder engagement
- 5.1 Develop new partnerships

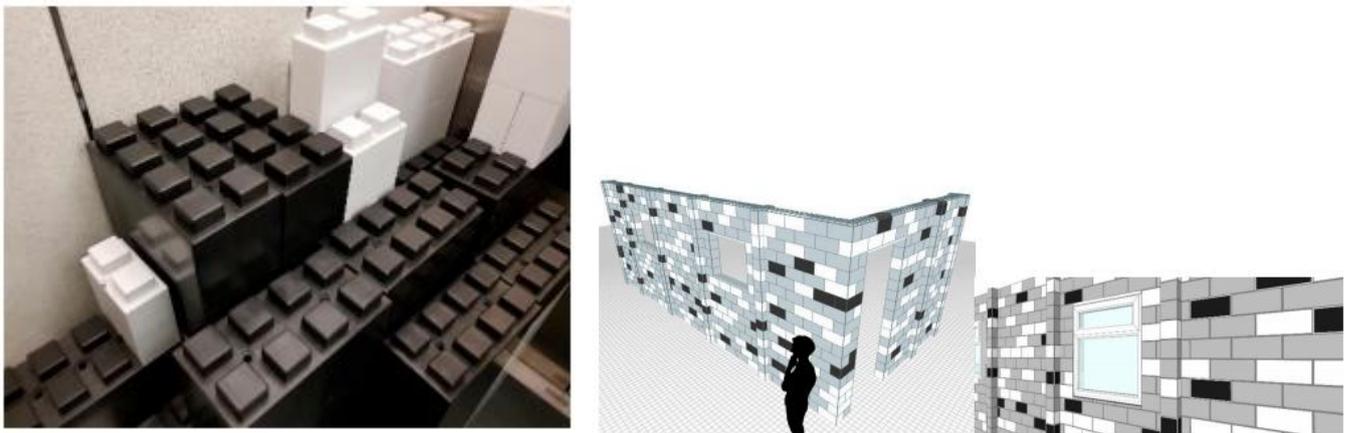
All equipment and furnishings have been procured and the Living Lab has been fully operational since 31st July 2018. Equipment has been refreshed this year, with updated software licenses being purchased for eye tracking equipment. This is necessary to support the increase in usage of the living lab and the services it provides.



Figure 2 showing the environment and equipment developed as part of this proposal.

The main environment within the living lab is a large reconfigurable seating/ discussion area, with private spaces for eye tracking and brain computer interface (BCI) experiments, a virtual immersive environment for research into virtual and augmented reality, and a control room (hidden by one-way

mirror) to both observe participants and house monitoring equipment. Within the physical design of the living lab, effort has been focused on the design and procurement of a flexible/reconfigurable environment based on a modular building block solution. The team have procured a modular building solution (Figure 3) to understand how this innovative solution can be used to facilitate the various private spaces and control areas required to implement the living lab spaces. The reconfigurable space includes a one-way mirror to observe the participants and create a private area for storage of monitoring equipment. To capture user interaction with the technology, a CCTV system based on four pan, tilt and zoom cameras have been installed. This solution can record back to the control centre behind the one-way mirror and allows capture of all elements of the user interaction undertaken in the environment. Figure 3 illustrates the Everblocks used within the living lab.



**Figure 3. The Everblocks modular building blocks used to create the reconfigurable space.
This includes 1 way mirror glass.**

The living lab includes state-of-the-art technologies which can be used to assess usability and offers participants various interactions. To date, this task has focused on the procurement and configuration of sensing equipment to monitor galvanic skin response (GSR), heart rate (HR), electroencephalography (EEG), eye tracking, and gross physical movement. The living lab is fully functional and makes use of a suite of technology. This includes 4 x Emotive Epoch EEG caps, 4 x Empatica e4 (GSR/heart rate sensors), 4 x Shimmer GSR sensor, and associated software. Simulation tools have also been purchased to allow clinical situations to be replicated. This includes customised human geometry hardware and associated Labview biomedical toolkit. Additionally, a state-of-the-art solution for eye-tracking (Tobii Pro Glasses 2,) has been procured and is currently being evaluated in a number of use cases, including sport analysis, driver alertness, and transport. To process and store the vast amount of data that can be generated by this technology, we have procured a high spec server which has now been configured to collect and store this data. To complement this, a data annotation tool (DANTE) has been procured and configured to assist in producing annotated datasets. This tool will allow for annotation of the data collected from the sensor solutions which can then be appropriately interpreted, and inference can be drawn. Additional equipment and resources have been procured to allow for the recording of user behaviour in engagement with m-health apps. This includes a number of tablet and high spec personal computers. Additionally, interactive technologies, including virtual reality equipment and Oculus Go, and tele-presence devices have been procured.

Personal and Public Involvement (PPI)

Multidisciplinary research and co-creation are at the core of the living lab methodology. To date 13 multidisciplinary projects have engaged with the living lab to understand the problem area, evaluate the solution and provide recommendations/ new ideas to solve the problem. Each project brings its own set of stakeholders. These come from a range of sectors and backgrounds including private, public and voluntary sectors. In total, projects using the living lab have involved around 180 participants. These projects have made use of a range of facilities available within the living lab. Outputs have varied from literature reviews, usability assessments, ideation events, market assessments, data collection and training events. This is summarised in Table 1 below with summaries of the projects provided in the following sections.

Project Description	Equipment Used	Stakeholders Engaged	Outputs
iMPAKT- Evaluation of mobile app to measure person centeredness.	Living Lab Environment Cameras Smartphones/ Tablets Eye-tracker Staff	Clinicians (x2) Researchers (x3) Software Engineers (x1) Care givers (x5) People living with dementia (x5) University Staff (x4) Total: 20 Stakeholders	Usability Assessment Product Recommendations
Connected Health Living Lab (CHIC)- Evaluation of app for detecting early signs of Diabetic foot disease.	Living Lab Environment Staff	Researchers (x8) University Staff (x5) Software/Hardware Engineers (x3) Post graduate students (x10) Volunteers (x22) Total: 48 Stakeholders	Research Paper Written Report Prototype
BTIIC- Eye tracking to measure and improve usability of YouView set top box.	Living Lab Environment Eye tracker TV equipment Observation area	Researchers (x2) Participants (UU Staff x15) Total: 17 Stakeholders	
Eye tracking to understand how Dyslexia affects how students write and interpret code.	Living Lab Environment Eye tracker	1x Ulster Researcher 28x Participants Total: 29 Stakeholders	Research Paper
Brain Computer Interface- Use of BCI equipment to control a user interface.	Living Lab Environment Emotiv BCI equipment	Ulster researchers (x2) Participants (x5) Total: 7 Stakeholders	Research Paper
InspireD- Usability assessment of reminiscence app for People living with Dementia	Living Lab Environment Cameras Smartphones/ Tablets Eye-tracker Staff	Researchers (x6) Clinicians (x4) Dementia Charity (x4) Outside company of app designers (x4) University Staff (x6) Care Givers (x8) People living with early on set dementia (x8) Total: 40 Stakeholders	Usability Assessment Product Recommendations
Apps for Dementia- Training on the importance of UX/UI and use of Eye tracking	Eye tracker Staff	Researchers (x2) Participants (x12) Total: 14 Stakeholders	Review of literature
Health Union Technologies- Digitising information from non-connected health devices.	Smartphones/ Tablets Staff Health Devices	Researchers (x3) Clinicians (x2) Community Nurses (x4) Outside company in healthcare solutions (x1)	User workshop Prototypes Written report Product Recommendations

		Technologists (x2) Total: 12 Stakeholders	
Kraydel KTP - Usability assessment of set top box to support independent living.	Living Lab Environment Smartphones/ Tablets Eye-tracker	Researchers (x1) Participants (x5) Total: 6 Stakeholders	Usability Assessment Product Recommendations
Assessment of COVID 19 Symptom tracker apps	Smartphones/ Tablets Staff	Researchers (x3) Technologists (x1) Volunteers (x2) Total: 6 Stakeholders	Research Paper
IncluSilver- Usability and personalisation of Dash4You dashboard	Living Lab Environment Cameras Smartphones/ Tablets Eye-tracker Staff	Researchers (x5) Industry Partners (x2) Participants (x5)	Usability Assessment Product Recommendations
PhotoFit- Extraction of accurate body measurements from single smartphone photo.	Smartphones/ Tablets Staff	Researchers (x2) Company Partner (x1) Participants (x2) Total: 5 Stakeholders	Market Analysis Prototype Funding Application
PhD project usability assessment of AEDs	Living Lab Environment Smartphones/ Tablets Eye-tracker	Researchers (1x) Participants (x40) Total: 41 Stakeholders	Research Paper Product Recommendations
PhD project to automatically detect agitation in People with Dementia	Living Lab Environment Observation Area TV equipment	Researchers (x1) Participants (x15) Total: 16 Stakeholders	Research Paper

Table 1. Summary of the projects which have engaged with the living lab including the equipment and resources they used, the stakeholders which were engaged, and the outputs produced from this engagement.

Findings

As mentioned previously, the Living Lab has been used by 13 cross disciplinary collaborative projects. A summary for each of the projects can be found below.

- **iMPAKT: Implementing and Measuring Person centredness using an App for Knowledge-** Is a multidisciplinary project between the Institute of Nursing and Health Research and School of Computing at Ulster. It is developing an app to measure person centeredness from nursing staff, initially in Cancer care services. The project has been using the Living Lab during the design phase of the project to ensure usability of the app is maximised. The Project is being funded by MacMillian.
- **Connected Health Innovation Centre (CHIC)-** CHIC has been using facilities within the Living Lab for a number of its multidisciplinary industry focused projects. In particular, CHIC has hosted PPI events within the lab for CHIC5_3: Development of a technology solution for the detection and prevention of Diabetic foot disease. This is a collaboration between industry partners, LAVA, Ballee Community pharmacy and In Your Element in collaboration with the Podiatry department and the School of Computing at Ulster. Researchers have held 2 events within the lab where end users have collected thermal images of their feet using a mobile thermal imaging solution, developed within the project. In total over 22 participants have engaged through this project.
- **BT Ireland Innovation Centre (BTIIC)-** The BTIIC project, a collaboration between BT Ireland and Ulster University, has been making use of the state-of-the-art eye tracking technologies offered through the Living Lab. These technologies are being used to measure and improve the usability of the company's YouView set top box.

- Dyslexia in Programmers- Eye tracking technologies, procured through the lab, are also being used to measure differences in how computer science students read code.
- Brain Computer Interface Study- The environment is being used as an environment to undertake testing and research into the development of Brain Computer Interface technologies. This testing requires a private and quiet environment in which to undertake testing. In addition, this project is utilising the Emotiv epoch BCI caps purchased through this project.
- Knowledge Transfer Partnership with Kraydel Ltd. – Funded by Innovate UK (2019-202). Total Funding to Ulster £242,280 ‘Development of an AI Based Platform and Service Solution to Support Independent Living and Promote Wellbeing’. The project provides the Knowledge Base Partners a significant opportunity to further enhance their leading-edge research and its practical application in AI (particularly ML) in addition to in the areas of conversational user interfaces and cognitive behavioural concepts in developing a novel digital chatbot and gamification interface to improve health and emotional wellbeing.
- REMIND Project- In order to maximise the impact of CH:LL we have begun discussions with other Living Labs across Europe, namely the Smart Lab at University of Jaen (Spain), the Human Health and Activity Laboratory, Lulea (Sweden) and Halmstad Intelligent Home at Halmstad University (Sweden). This network of Living labs, facilitated through the Horizon 2020 project REMIND, will allow for the sharing of best practices in the design and evaluation of Connected Health Solutions in addition to allowing developed solutions to be evaluated with an international cohort. This has resulted in the publication of a conference paper detailing this sharing of ideas- <https://www.mdpi.com/2504-3900/2/19/1241>.
- InspirD- The InspirD app, supported through the Public Health Agency Research and Development Office and Atlantic Philanthropies (COM/5016/14). Carried out a usability evaluation on their app with people with dementia.
- PhD Projects- The living lab equipment has been utilised by PhD researcher Hannah Torney within her project, Usability engineering methods for assessing and enhancing the human-machine interaction of automated external defibrillators. PhD Researcher Fiona Marshall, used the Living lab to conduct experiments aiming to examine how technology can be used to automatically identify agitative behaviors in people living with dementia. Fiona used the lab’s equipment, including the 1 way mirror to observe participants as they carried out a number of set tasks.
- Health Union Technologies- Researchers from the CHLL ran a workshop with 5 clinical staff to examine the potential and barriers of technology to capture data from traditional non-connected health devices (Blood pressure monitors and Pulse oximeters). Researchers identified technologies to digitise such information and provided some demonstrations of these solutions during a workshop at Craigavon Area hospital.
- COVID-19 Symptom Trackers- Researchers at CHLL undertook an evaluation of the quality of COVID-19 symptom tracker and track and trace apps. The team evaluates apps available in NI and UK using the Mobile Assessment Reliability Scale.
- Inclusilver- Medea SRL, approached the CHLL lab to provide expertise in usability assessment and design of personalised interventions. CHLL researchers provided a Usability evaluation on the companies product (Dash4You) and produced a set of recommendations for how the Solution could be personalised through the use of ontologies.

- PhotoFit- Researchers in CHLL undertook a market assessment and feasibility study to examine the potential of extracting accurate body measurements from a single picture taken from a smartphone. This project was undertaken for Luke Steele as part of an innovation voucher. The team has since supported Mr Steels in applying to Tech start for additional funding to further develop the proof of concept.

Conclusion and Recommendations

This project aimed to provide a unique environment to support multi-disciplinary research in the area of connected health. Establishment of the lab environment furnished by a suite sensorised and state of the art recording technologies has successfully realised this vision. The environment has fostered a collaboration between Computing, Nursing and Engineering and has further developed the Connected Health research agenda at Ulster University.

Throughout the duration of the Project, 13 Projects and their respective stakeholders engaged with the Living Lab. All of the Projects benefitted from the environment, having access to state of the art equipment and the knowledge from the research team. As a result of these engagements over 180 stakeholders were exposed to the environment leading to a diverse range of outputs. Activities were also extended through international partnerships where generalised recommendations of usage of the environment and how to store and process recorded data were made.

Following the successful establishment, usage and evaluation of the lab, the following key recommendations have been made:

- the living lab as a concept has not been fully exploited within the domain of Connected Health. This Project has clearly demonstrated the benefit of the concept and also re-affirmed that Living Labs are a methodology and not simply a physical environment. They should offer a pathway through the development cycle including user needs elicitation, design, development, evaluation and business modelling including stakeholders at each stage.
- Usage of the living lab by such a broad range of projects has demonstrated the utility of a such an environment. A recommendation is that any further connected health type Projects should make use of this resource in their ongoing work and proposal development to avoid duplication of efforts and to maximise the skill set, knowledge and state of the art technologies which are now in place.
- as mentioned, a living lab is a methodology, not necessarily a fixed physical environment. This Project exploited the nature of both reconfigurable physical and operational spaces and has benefitted immensely from this during the recent re-location of the School of Computing from the Jordanstown campus to the new Belfast campus. A new facility has been created within Northland House as part of the proposals for the Centre for Digital Healthcare Technologies under the auspices of the Belfast Region City Deal.
- to maximise the impact of the findings from the work, creation of a network of international partners with similar objectives offers benefits to assist in the standardisation of approaches and sharing of best practices.

In summary, the Connected Health living lab has become an integral component of the Group's research strategy and is expected to remain at the centre of the agenda for the short-medium term.

