The Use of Digital Smart Sensors Technology in Early Detection and Monitoring of Air- Borne Infection in British Hospitals?

The Dilemma...

Dr Ghasson Shabha and Associate Professor Chris Conway from the Integrated Design and Construction (IDC) centre at CEBE; Birmingham City University investigated the latest development of incorporating smart sensors technology (SST) in monitoring and detecting airborne infection in British Hospitals. They argued that effective incorporation of SST in this digital age are the *sine quo non* for any infection control strategy in mitigating such endemic problem but can smart sensors be the "panacea for hospitals 'ills" ?

Ghasson Shabha (full title and contact details)
Chris Conway (full title and contact details)

IDC
School of Engineering and the Built Environment
CEBE
Birmingham City University

Hospitals are closely fitted buildings encompassing a wide range of specialized highly serviced spaces which are built for purpose encompassing complex organisation and make them very difficult to manage. This is particularly true given that hospital environment can be a reservoir for potentially infective agents which need to be controlled and managed effectively due to the complex matrix of activities and diverse range of users including visitors, patients and staff increasing the likelihood of cross infection. This might prove to be detrimental to vulnerable patients of pre-existing health conditions (e.g. immune suppressed). This is given that Air borne infection is attributed to a wide range of bacterial and viral infection. Methicillin resistant *Staphylococcus aureus* (MRSA) and C Difficile in particular are the most prevalent bacteria of UK hospitals together with other organisms, remain a cause for concern over increasing incidences and fatalities due to healthcare-associated infection (HCAI). It has penetrated virtually every hospital and chronic endemic state remains in most with episodes of cross-infection and sporadic outbreaks. One in 16 patients is developing infections on NHS wards because of poor hygiene among staff, according to National Institute for Health and Care Excellence (NICE). It was claimed that 800 patients a day – or 300,000 a year – are infected by a member of staff or by dirty equipment. It is estimated the infections caused 5,000 deaths annually and contributed to another 15,000 due to MRSA and C Difficile (The Daily Mail, Feb 2016)

This article assesses the *rasion detre* and the effectiveness of using digital smart sensors technology in mitigating the spread of air borne infection (ABI) in British hospitals; it primarily seeks to address a number of key questions:

- How can the spread of ABI be effectively controlled and managed on a day-to-day basis to reduce prolonged treatments and avoid fatalities?
- How effective and instrumental are digital technological interventions in detecting and monitoring ABI in hospitals?
- Are these interventions cost effective given the current NHS deficit?
- Is there a need for interdisciplinary approach where built environment (BE) professional and clinicians in addressing such increasing complexities of tackling air-borne infection in the light of the wealth of evidence-based knowledge generated over the past 10 years?
- What new roles and responsibilities can be proposed to ensure that BE professionals and clinicians acts as “knowledge integrators” and “Facilitators” in tackling ABI using evidence based physiological markers and patients well-being/psychometric indices?

An attempt will be made to explore and assess the efficacy and viability of some cutting edge technological interventions concomitant with routine day-to-day management infection control protocols.

Introduction:

Hospitals are closely fitted buildings. They can be depicted as an array of many interdependent and interwoven technologically complex services; human and environmental control systems and their many processes, interactions and influences. Being both complex and highly serviced make them very difficult to manage and control. Specialised and highly serviced spaces like operating theatre (OT) and Intensive Care Units (ICU) in particular are intrinsically highly specific due to the very nature of activities performed. These are designed to fit the exacting clinical environmental requirements i.e. to be and sterile and infection free, for a surgical team to operate, implying a high running and maintenance cost to meet these requirements and to comply with strict Health and Hygiene rules.

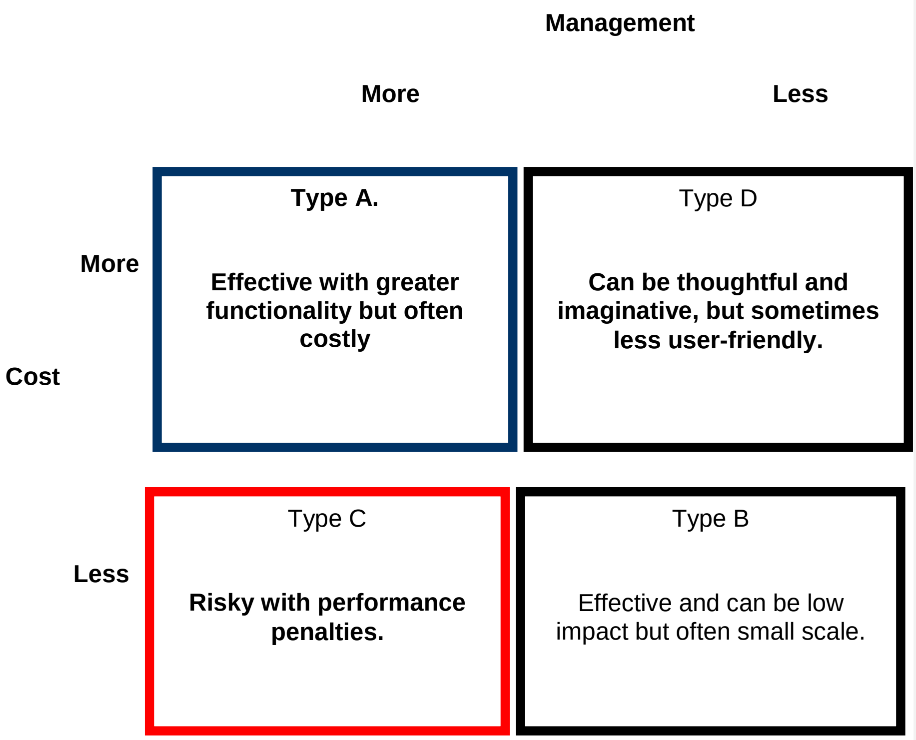

Figure 1: Technological Complexity of Buildings (Bordas & Leman 2001)

The relationship between host and the internal environment is reciprocal and e critical as this might contribute to and accentuate HCAI. However, when hosts- the primary source of cross-infection are factored into any equation the laws, which represent logic, are constantly being moved and become more difficult to predict and manage.

Mode of transmission can be envisaged through direct contact, cross-contamination, air-borne, a combination of both as shown in table 1 below.

Modes of Transmission	Possible Culprits	Current Technological Technology Intervention	Sensors
Direct Contact	Carriers (patient, staff, visitors) furniture, room equipment, curtains,	Screening upon admission Hard surface detection	
	Infectious Agent (organic substance)	Decontamination, sterilising, disinfecting	
	Objects		
Cross-contamination	Equipment/ devices (ventilator, peripheral catheter, urinary catheter, mechanical ventilator, parenteral nutrition, blood pressure cuffs, stethoscope)	Silicon membrane Long-term, hard- wearing surfaces which contain anti-bacterial properties (copper, silver coating technologies) Antibacterial and disinfectants products Smart paints and antibacterial emulsion	
	Sanitary appliances		
	Floors, walls and other hard surfaces		
Air-Borne	Hospital dust circulated through mechanical ventilation & Ac systems (filters, internal wall of ducting, diffusers)	Design of isolation rooms held at negative pressure to reduce aerosol escape to those outside the room and a higher air-change rate to allow rapid removal of aerosols Use of Ultra-violet Irradiation method	
	Air pressure differentials in areas where infected patients is kept [1]		

[1] Techniques such as aerosol particles tracer sampling and computational fluid dynamics can be applied to study the performance of negative pressure rooms and to assess how design variables can affect their performance.

Figure 2- Modes of Transmission

Several design characteristics influencing the outbreak of infection have been identified in literature including wards design, beds occupancy[2] and intensity of use of hospital area. In the past, hospital design focused on low cost per square meter; this was based on models of nursing care derived from industrial settings, where the transmission of infection was not the primary consideration (Butcher, 2006) New design models have been developed subsequently to address these deficiencies to ensure patients safety and to minimise the likelihood of cross-infection due to sharing facilities and medical equipment. Design factors can indirectly affect the mode of transmission the daily operational and activities in various areas in a hospitals by patients and staff and affect the pattern of use of space fittings, medical equipment and devices and furniture leading to cross-contamination.

By the same token, both beds occupancy and intensity and frequency of use of hospital area will impact on proximity and closeness of patients involved. This is more likely to increase cross contamination. Staff daily practices and process might be another trigger

"Patient rooms or treatment rooms do not have sinks in which healthcare worker and visitor can wash their hands. Sinks located in inaccessible place".

Recent study in the US emphasized the importance of using private room and the installation of more sinks to encourage frequent hand washing to reduce the impact of HCAI[3]. In one instance it was claimed that HCAI or "nosocomial" [4] infection rates decreased by 11% since the opening of new built hospital. (Van

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[2] Government target has led to higher bed occupancy whilst staff shortages and increased use of unqualified staff have compounded strict hygiene protocols. (www.bbc.co.uk 2006)

[3] This is referring to Bronson Methodist Hospital in Michigan which is part of Pebble Project.

[4] Originating or taking place in a hospital, acquired in a hospital, especially in reference to an infection.

According to Webster's Medical Dictionary the term "nosocomial" comes from two Greek words: "nosus" meaning "disease" + "komeion" meaning "to take care of." Hence, "nosocomial" should apply to any disease contracted by a patient while under medical care. However, "nosocomial" has been whittled down over the years and now just refers to hospitals -- it is now synonymous with hospital-acquired infection. Nosocomial infections are ones that have been caught in a hospital. A nosocomial infection is specifically one that was not present or incubating prior to the patient being admitted to the hospital, but occurred within 72 hours after admittance to the hospital.

Enk, 2006). Other broad design measures to reduce HCAI have been proposed by the American Institute of Architects (AIA) in their new guidelines including, *inter alia,* separation of patients with communicable disease in damp-dusted areas which are separately ventilated and securing a safe clinical environment and appropriate provision of isolation rooms and facilities. Hospital speciality[5] and ward speciality[6] has also been observed to be relevant as much as the building type. Early indications based on the level of infections recorded in General Acute speciality hospitals in England over the last five years is quite overwhelming. **AE**, **ICU, endoscopy and internal wards** are more susceptible to infection than others. This remain to be tested

Design Variables (Extraneous & Independent Variables)	
Descriptive Design Variables	Independent Design Variables
Hospital Design	Proximity of beds
Ward Design	Sharing facilities
Bed Occupancy	Number of beds
Hospital Speciality	Technicality of clinical procedures
	Mechanical Ventilation
Ward Speciality	

Air Borne Infection:

[5]
'Single speciality' Trusts (lowest on AIR BORNE INFECTION)- (Trusts undertaking orthopaedics, or cancer or children health services).
'Specialist' Trusts- (Trusts with specialist services which receive patients referred from other Trusts for these services.
'General acute' Trusts- (Trusts providing general acute healthcare services). The highest in the AIR BORNE INFECTION.

[6] Ward speciality can be categorised into medical, surgical, obstetrics and gynaecology, critical care medicine amongst many others specialties. (Hospital Infection Society and Infection Control Nurses Association, 2007: 9)

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Most patients spend up to 90% of their time indoor. Much emphasis was made regarding indoor air quality. The link between the cleanliness of the air, its level of ionization and the performance of people working in the conditioned space (MacRae, 2007, Mendell, M.J ,2006.2008). Different types of contaminants and pollutants can be found in buildings including particulates (dust, pollen), gaseous (Volatile Organic Compounds (VOC) and odours) and microbiological substances (mould, fungi, mildew, bacteria and viruses) (Kilcoyne, 2006; www.colorado.edu/today/2015/04/20/researchers-produce-first-atlas-airborne-microbes-across-united-states). These have been identified in hospital environment. Interestingly enough these been considered to be a frequent component of hospital dust as they it can easily circulate through the air supply and return The spread of infection.via medical equipment and appliances such as ventilator, peripheral catheter, urinary catheter, mechanical ventilator, parenteral nutrition, blood pressure cuffs, stethoscope amongst many others has also been highlighted in the literature (Health Protection Agency, 2006; Health Infection Society, 2008) ventilation systems which poses a major risk of cross-infection?

The spread of infection.via medical equipment and appliances such as ventilator, peripheral catheter, urinary catheter, mechanical ventilator, parenteral nutrition, blood pressure cuffs, and stethoscope amongst many others has also been highlighted in the literature (Health Protection Agency, 2006; Health Infection Society, 2008)

The situation has been exasperated due to the need conserve and optimize energy efficiency and reduce of carbon emission. This has essentially reduced natural ventilation from fresh air which is currently below latest requirement of Part F of Building Regulations to be 12 L/ person to achieve the recommended fresh air requirements sec as shown in table 3.

Hospitals are becoming more **airtight and warmer** to comply with part F and L of Building Regulation; this has compromised indoor air qualities significantly increasing the risk of air-borne infection in sensitive hospital areas like Bone Marrow Transplant, ICU and AE areas The changes in energy efficiency regulations require buildings to be 'better sealed' and 'more airtight'. The new Part F Document provisions have been designed to ventilate buildings having air permeability down to $3m^3/h/m^2$ at 50 Pa, allowing designers to plan to 'worst case scenario' as Buildings Regulations document Part L allows air permeability up to 10 $m^3/h/m^2$. As hospitals are becoming more air-tight and warmer, they are more likely to require air-conditioning systems which will be energy inefficient and costly to run

Air space per person	Air supply per person	Air changes per hour (ACH)
$3m^3$	17 litre/s	20
6	11	6.5
9	8	3.2
12	6	1.8

Table 3: Recommended minimum fresh air supply (www.vent-axia.co.uk)

Environmental conditions can affect the survival and persistence of microorganisms on indoor surfaces. (Mendell, M.J, *et al*, 2006; 2008) Controlling indoor temperature and RH to an acceptable level minimizes microbial growth and results in consistent thermal comfort in the occupied space. RH is known to influence microbial survival and growth such as mould, mildew and bacteria inside ductwork and ventilations diffusers leading to high concentration of the production of allergens, odour and toxins in the ambient environment. It has been suggested that maintaining internal relative humidity below 60% significantly reduces the potential for microbial growth in buildings (Kilcoyne, 2006)

The ability of some bacteria e.g. *Mycobacterium tuberculosis* (TB) to persist in indoor environment (Skoog, 2006; Cornet, *et al*, 2007 Fleischer, *et a*l, 2006). Interestingly, both Listeria and Salmonella thrive on higher humidity levels. In theory, the accepted limits for ventilation and air-conditioning [7] are 21° C to 24° C at 40% to 60% relative humidity; but in reality humidity levels can be much lower than 40% in many hospital wards (NHS, 1994). Non-humid environments appear to be optimal for to thrive given that the comfort zone 21° C to 24° C is well within the survival temperature range of 18-37° C. What measures can be undertaken to reduce the impact of indoor temperature and relative humidity (RH) on the survival of. What improvement can be made to ventilation systems to reduce the spread of and other air borne infection?

Technological Interventions: The Need for Holistic Approach

There seems to be a multiplicity of interrelated factors involved in the spread of infection in clinical environment. Any attempt to disentangle these factors independently in order to measure their impact on patient well being will be onerous and almost entirely difficult to achieve in practice. Past methods of interventions were either preventive or corrective. It appears that the methods are highly fragmented and expediently applied on *ad hoc* basis to meet the immediate short term Agenda of clients and their organisations. These methods are largely based on insufficient and anecdotal evidence, claims and observations with a few exceptions. Most preventative intervention methods are prescriptive in their scope ignoring the role of human factor as a host in spreading infection. The impact on susceptible patients appears to be interwoven: one particular factor might simultaneously act as a trigger for another which necessitates a new modus operand and a paradigm shift.

Cross infection (Hard surfaces):

Cleaning:

Methods of intervention vary in their scope, efficacy and effectiveness in tackling the spread of infection which include both preventative and corrective.

[7]

The former were developed primarily to inhibit the growth and proliferation of bacteria by providing long-term, hard- wearing surfaces, which contain anti-bacterial properties. Several products have been introduced into the UK market purported to be most effective which include, Biocote, Addmaster and Dulux antibacterial paint amongst many other products

Greater reliance on antibacterial and disinfectants products on internal surfaces is critical factor in infection control. The efficacy of these methods is determined by accessibility of antibacterial agent/additives at the coating/bacteria interface; this is mainly based on slow release of the agent to maintain an effective concentration at and near the surface of the material.

“While hospitals have taken deep-cleaning measures to eliminate superbugs such as MRSA, there are fears staff may have failed to carry out more basic routine hygiene measures to control other infections. (NICS , 2016)
Using wearable sensors to get real time data when it comes to monitoring cleanliness like washing hand. The device and the app will be able to alert you when you experiencing an asthma situation, journaling, treatment plans, displays, and the tracking and information on the treating of symptoms.
www.valedotherapy.com

Other infection control strategies have been devised to reduce infection by improving procedural/managerial measures to ensure that safety and well being of patients is followed through. There is a growing recognition that implementation of new surveillance; screening and detection systems may prevent further spread of ABI (HSC 2000/002, 032).

The demands for emerging medical technology conflict with the needs to control the spread and contain micro-organism which might lead cross-contamination. However, it was observed that at a relative humidity
Humidity level of the internal surface and porosity of the surface are conducive to growth and spread of infection. Makison (2006) however found that survival actually had more to do with material type than RH.

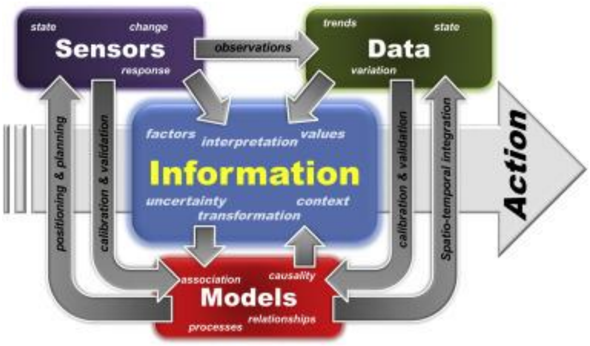
Other possible management strategies for tackling the risk **air borne infection** mainly ducting in ventilation and air-conditioning system including mainly I) filtration, ii) deep cleaning via steaming and iii) UVGI regime (Ryan et al, 2011). Again the efficacy of these methods and robustness is determined by accessibility of to the Labyrinth of mechanical ducting which proved to be problematic .A typical system includes air filters, air cooling, chilled water systems de-humidifiers, humidifiers, duct work, dampers and diffusers, fire dampers and sound attenuators.

Steril Aire created a "kill tunnel" model (Spicer, 2016) which enable effective use of UVC in normal HVAC conditions for an acceptable kill rate in commercial & NHS facilities though it will not be to provide a log 6 protection.

How can Steril model benefit from ubiquitous sensing using smart sensors technology for early detection and monitoring?

A combination of more one or two methods might be appropriate cost permitted. Cyclical duct cleaning is needed to dislodge accumulation of dust most of which will be of a higher proportion of organic compounds (OC) including hair and skin flakes- the main nutrients for micro-organisms- A major fire hazard.

Smart Sensors:



The authors argue that digitised smart sensors are critically important to assess and quantify the effectiveness of any technological interventions mitigate impacts on clinical environmental and patient’s health.

Suffice to mention that sensors are becoming ubiquitous in everyday life, generating data at an unprecedented rate and scale which is self perpetuating.

Models are essential tools to understand processes, identify relationships, associations and causality, formalize stakeholder mental models, and to. They can help to explain data, as well as inform the deployment and location of sensors by identifying hotspots and areas of interest where data collection may achieve the best results.

Despite being viewed as 'black boxes' that obscure complexity and lack transparency are vital tools which can be used to resolve (McIntosh et al., 2007). However, models should be seen as technologies that can help in any step of the scientific process of understanding and solving complex systems problems. models should be seen as virtual reality technologies for a global system science in which sensors serve the fundamental sensing function for (i) understanding system dynamics, (ii) early detection and response to system malfunctions, and (iii) building resilient systems via enhanced adaptive management approaches that learn from past events and associated decision alternative based on reaction-diffusion-dispersal processes and information theory.

Ways Forward:

A more holistic and a multi-strategy design/ human management strategy based on sensors technology is needed for tackling the spread of air borne infection needed. to simulate the mechanism of how infection colonies spread in existing hospitals and to provide in-depth understanding of any outbreaks are directly related to the cleanliness of internal finishing, fittings and ducting,

In any strategic formulation two questions need to be addressed: Where are we now on day-to-day screening? Where are we now on cleaning management? And where are we heading? The first part will require a more strategic analysis whether we need to identify the source of infection or the carrier --more control including screening and detection of patient/visitors/ staff carriers - i.e. a more users-focused approach to cross infection

Well-informed decisions about the selection and use of materials specifications for internal finishing reducing cross-contamination BE professionals must be convinced about the risk associated with specifying finishing materials as this can potentially lead to spread and colonisation of microorganisms. The immediate internal environment can be a reservoir of microorganisms and source of infection. Equally the spread through ventilation and air-conditioning systems cannot be underestimated. A robust monitoring and detection method over the lifespan cycle of NHS premises and facilities is needed. An in-depth understanding of the mechanism of how the infection is spreading through environmental services systems. This might include a proactive involvement of infection control team and facilities managers at the early design stage.

Integration of models by incorporating robust smart sensors can contribute to harnessing ‘Big Data’ to ‘Big Information’ to inform NHS decision makers to effectively address the endemic problem spread of infection in clinical environment which will have a far reaching benefits to debilitating health of vulnerable patients and users. A robust model depicting and monitoring the process of infection transmission through critical hotspots and areas in hospital environment is needed. Data can be compared to a benchmark to support performance prediction according to the extent and frequency of occurrence.

An automated system for processing, storage, analysis, validation and presentation will also needed, calibrating and recording data, which might affect the outcome.

Measurable evidence-based data physiological parameters and comfort/well-being+ indicators need to be incorporated into building management system which necessitates a serious paradigm shift. The old adage of IAQ adequate for “comfort” must be intertwined with IAQ to mitigate the risk and improve patients’ health. The Health Patch MD is a new technology for healthcare professionals to be able to keep tabs on the vital information of their patients. The company behind this product is called Vital Connect. The HealthPatch MD is a biosensor that is reusable and it is embedded in a patch that can be disposed of. It has

ECG electrodes and also has a 3 axis accelerometer that helps with keeping track of heart rate, breathing, temperature, steps, and even detects body position in case if a person has fallen. www.vitalconnect.com

Closer participation and partnership between BE professional and clinician to optimize indoor air management for the benefit patients is needed as air-borne infection and Indoor air quality are intertwined and mutually related. Equally there is a need to correlate IAQ data to occupant health information. and understand patient symptoms associated with poor IAQ. This requires training of clinicians to be aware of the issues related to hospital environment.

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