Mapping digital transformation in building performance assessment and management – commercial activities for the operation phase

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Abstract. Having in mind both the possibilities (e.g. automatic analysis of complex data to increase building performance and automation of difficult/dangerous/repetitive traditionally human tasks using machine learning/data mining/artificial intelligence and sensors) and challenges (e.g. regarding: privacy, security, safety), the main aim is developing an approach to structure the various commercial activities, for the time being in a non-comprehensive manner, related to the digital transformation of the built environment and assess the current state of technology in terms of products, services and solutions.

1 Introduction

By the year 2020, an entire generation, Generation C (for "connected"), will have grown up in a primarily digital world. Computers, the internet, mobile phones, social networking — all are second nature to members of this group. The effects of an increasingly digitized world are now reaching into every corner of our lives. [1]

Buildings make no exception. The futuristic perceived concept of smart buildings is already a reality today in many buildings across the globe and is creating new experiences for building operators and occupants alike. The maturity of state-of-the-art hardware and software finally allows researchers and industry to pilot and implement working solutions for real-world and large-scale contexts. The available and rapidly emerging new digital technologies are also enabling to assess in real-time, inter-relate and visualize/ communicate to stakeholders crucial aspects of overall building performance, including indoor environmental quality, performance aspects relating to user satisfaction, and well-being and (where applicable) productivity, resource-efficiency, compliance with specifications and contractual requirements, profitability, certification levels, and – ultimately – market value.

In a natural or forced response the industry landscape [2,3] is reshaping and traditional manufacturers are shifting their businesses. Moreover, technology companies are entering the buildings market as new players and are apparently having a disruptive effect in terms of technology being installed and used in buildings. EU policy is also undergoing a similar response. For example the revised Energy Performance of Buildings Directive (EPBD) [4] introduces provisions on automated Technical Building Systems inspections and a new tool the Smart Readiness Indicator (SRI) [5].

In terms of research there is a lot happening in this field. This point can be easily illustrated just by looking at how Europe's Horizon 2020 framework programme alone is supporting research, innovation and market uptake of smart buildings, although this frequently used term is ill-defined [6]. The searching and mapping of EU projects was carried out during April and early May 2017. The final results of the research [7] have found 42 relevant Horizon 2020 actions, funded across 28 topics, the majority of which are Research and Innovation Actions (RIA) and Innovation Actions (IA). The total budget costs for these 42 actions add up to 367.9 million Euros, of which the EU grant contribution is 304.1 million Euros.

The authors of this paper identified the need to focus on commercial activities available today on the market owing to the following reasons:

- The diverse plethora of ongoing research activities most often remain disaggregated and thus uncaptured in comprehensive reviews;
- Too often in research activities the touch with reality is lost;
- Actual building performance is experienced by building operators and occupants alike and not the designed building performance.

With the above backdrop and arguments in mind the authors laid down the foundation for the mapping of products, services or solutions available today on the market, that have long passed the research phase and are continuously being improved based on "testing" by users in real life conditions.

2 Methods

In this paper, the terms digitization, digitalization and digital transformation are used as follows:

- Digitization as the process of making information available and accessible in digital format;
- Digitalization as the process of considering how to best apply digitized information to simplify specific operations;
- Digital transformation as the process of devising new business applications that integrate all the digitized data and digitalized applications) [8].

Although, the authors cover mostly digital transformation at times there is an expected overlap with digitalization.

The main scope of this paper is to capture two out of three key functionalities of the Smart Readiness Indicator [9], introduced in the revised EPBD [4], on one hand the readiness to adapt in response to occupant needs and on the other hand the readiness to facilitate maintenance and efficient operation. The third key functionality, the readiness to adapt in response to energy grids, shall be included in future papers. Even though, the SRI is a political instrument and digital transformation in buildings has a much wider scope than EPBD's technical building systems, the SRI will presumably act as a driver in the market, making it much more than just a political tool, similar to Energy Performance Certificates (EPCs), inspections and nearly Zero Energy Buildings (nZEBs).

In doing so, the authors focus on the operation phase of buildings for the purpose of this non-comprehensive mapping of current commercial activities related to the built environment and linked to the next phase in the digital revolution [10].

For ensuring a simple and easy to understand overview the authors propose a structured approach. The selected products, systems or solutions are displayed in a multidimensional array: aim of product, service or solution ↔ data source ↔ data science discipline. The considered data science disciplines are statistics, visualisations, patter recognition, data mining, machine learning, artificial intelligence (see **Fig. 1**).

All products, services or solutions included in this paper have been collected by the authors via internet research and include only publicly available information. There have been no enquiries of the organisations offering the products, services or solutions.

Although, it is obvious that moving from products and services to solutions implies a shift from features and benefits to value and that solutions integrate different products and services, for the purpose of this paper the three types of business offering remain aggregated. This is largely due to the fact that most often these offerings overlap and setting them apart is a challenging task.

Both non-residential and residential buildings are covered, the former due to their higher degree of complexity and the latter due to their sheer volume. Furthermore, the use cases are very different and most likely this is reflected in the available products, services and solutions.

3 Results

For each product, service or solution the following data has been collected: short name; product, service or solution; organisation; criterion 1 energy; criterion 2 convenience; market entry year; market penetration (no. of buildings); spread (country(ies), EU, global); reference(s). Being an internet research, not all information was available. This can be however further enquired from the organisations offering the products, services or solutions for being included in future updates in case this proposed approach picks up speed.

At this stage of testing this approach 40 products, services or solutions have been mapped in no particular order and without any filtering on the envisaged criteria:

[(short name) product, service or solution / organisation]

- **(BELOK OA)** BELOK Operational Analysis / BELOK;
- **(Indoors a)** Indoors analytics / Indoo.rs;
- **(Indoors p)** Indoors positioning / Indoo.rs;
- **(Indoors m)** Indoors mapping / Indoo.rs;
- **(SMHI FC)** SMHI Forecast Control / SMHI;

- **(JEM)** Johnson Controls Enterprise Management / Johnson Controls International;
- **(Leanheat)** Leanheat / Lenaheat;
- **(Watty)** Watty / Watty;
- **(OptiWatti)** OptiWatti / OptiWatti;
- **(Fourdeg)** Fourdeg / Fourdeg;
- **(Emphatic building)** Emphatic building / Tieto;
- **(My MCS SB)** My MCS Smart Building / Nemetschek;
- **(Axxerion)** Axxerion / Nemetschek;
- **(Locatee)** Locatee / Locatee;
- **(Thingsee)** Thingsee / Haltian;
- **(Yanzi)** Yanzi / Yanzi;
- **(Steerpath)** Steerpath / Steerpath;
- **(Teem)** Teem / TeemWeWork;
- **(Mapiq)** Mapiq / Mapiq;
- **(bGrid)** bGrid built to adapt / bGrid;
- **(BuildingiQ)** BuildingiQ / BuildingiQ;
- **(SE BA)** Building Analytics / Schneider Electric;
- **(Raybased)** Raybased / Raybased;
- **(Comfy)** Comfy / Siemens;
- **(Enlighted)** Enlighted / Siemens;
- **(FIN)** FIN framework / Siemens;
- **(Fibaro)** Fibaro / Nice Group;
- **(Lerta)** Lerta Energy Intelligence / Lerta Energy;
- **(SES)** Smart Energy Solution / S-Labs;
- **(Enerbrain)** Enerbrain / Enerbrain;
- **(Eve)** Evehome / Eve Systems;
- **(Netatmo E)** Netatmo Energy / Legrand;
- **(Netatmo W)** Netatmo Weather / Legrand;
- **(Netatmo A)** Netatmo Air Care / Legrand;
- **(Ambinode)** Ambinode / Leapcraft;
- **(Go IoT)** Go IoT / Go IoT;
- **(Healthbox)** Healthbox 3.0 / Renson;
- **(Tririga BI)** Tririga Building Insights / IBM;
- **(Tado H)** Tado Heating / Tado;
- **(Tado C)** Tado Cooling / Tado;
- **(SkySpark)** SkySpar / SkyFoundry;
- **(Digital TB)** Digital Test Bench / Synavision;
- **(Genesis64)** Genesis64 / Iconics.

The products, services and solutions have been mapped in two multidimensional arrays, one for the readiness to facilitate maintenance and efficient operation and the second for the readiness to adapt in response to occupant needs.

The multidimensional array for the readiness to facilitate maintenance and efficient operation has the following three dimensions (see **Fig. 2**):

- Aim of product, service or solution: continuous technical building systems optimization, boost business / space optimization, continuous heating optimization, continuous ventilation optimization, continuous heating and cooling optimization, improve occupant satisfaction, facility management, Internet of Things (IoT) platform;
- Data source: Building Automation and Control System / Building Management System (BACS / BMS), IoT devices (humans included), weather;
- Data science discipline: statistics, visualizations, pattern recognition, data mining, machine learning, artificial intelligence.

The multidimensional array for the readiness to adapt in response to occupant needs has the following three dimensions (see **Fig. 3**):

- Aim of product, service or solution: increase experience and satisfaction, tenant management, smart living and sustainability, increase well-being, happiness and performance, IoT platform;
- Data source: BACS / BMS, IoT devices (humans included), weather;
- Data science discipline: statistics, visualizations, pattern recognition, data mining, machine learning, artificial intelligence.

For easy visualization the third dimension is represented under the following colour code: **statistics**, **visualizations**, **pattern recognition**, **data mining**, **machine learning**, **artificial intelligence**.

4 Discussion

Some of the 43 selected products, services and solutions are included in both multidimensional arrays while some find themselves only in one of them. The multidimensional array for the readiness to facilitate maintenance and efficient operation includes 38 products, services and solutions while the multidimensional array for the readiness to adapt in response to occupant needs includes 31 products, services and solutions.

The proposed approach enables a simple and easy to understand overview of the selection of products, services or solutions.

Data privacy, security and safety is at the top of the agenda for all the products, services and solutions included in this paper. Some of them even leverages it into their unique value proposition (e.g. fully storing the data locally without cloud uploads). All the products, services and solutions offered in Europe need to comply as of 25 May 2018 with the General Data Protection Regulation (GDPR), which in turn most likely increases the clients' trust.

Many products, services and solutions entered the market around 2010, but mostly immediately after or in recent years. Only a few have been on the market since the early 2000s. Since then the market penetration of the products,

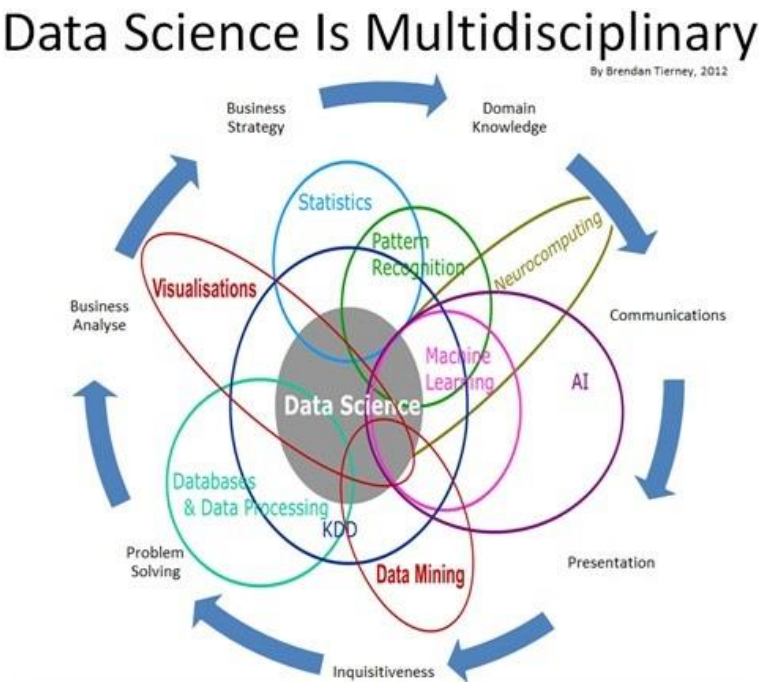

Fig. 1 The multiple disciplines of data science and the key skills of a data scientist (Brendan Tierney, 2012)

Data science discipline →	*Statistics*	*Visualizations*	*Pattern recognition*	*Data mining*	*Machine learning*	*Artificial intelligence*		
Aim of product, service or solution →	*Continuous technical building systems optimization*	*Boost business Space optimization*	*Continuous heating optimization*	*Continuous ventilation optimization*	*Continuous heating and cooling optimization*	*Improve ocupant satisfaction*	*Facilty management*	*IoT platform*
Data source ↓								
BACS / BMS	BELOK OA JEM JEM JEM bGrid bGrid BuildingiQ BuildingiQ BuildingiQ SE BA SE BA Raybased Raybased Tririga BI Tririga BI Tririga BI SkySpark SkySpark SkySpark SkySpark Digital TB Digital TB Digital TB	Mapiq Mapiq					myMCS SB myMCS SB Axxerion Axxerion Comfy Comfy Comfy Genesis64 Genesis64 Genesis64	Mapiq Mapiq Raybased Raybased Comfy Comfy Comfy Enlighted Enlighted FIN FIN Go IoT Go IoT
IoT devices (humans included)	bGrid bGrid BuildingiQ BuildingiQ BuildingiQ Raybased Raybased Enlighted Enlighted Fibaro SES SES Enerbrain Enerbrain Eve Ambinode Ambinode Ambinode Tririga BI Tririga BI Tririga BI	Indoors a Indoors a Locatee Locatee Locatee Steerpath Steerpath Mapiq Mapiq	Leanheat Leanheat Fourdeg Fourdeg Netatmo E Netatmo E	Healthbox Healthbox	OptiWatti OptiWatti Lerta Lerta Tado H Tado H Tado C Tado C	Emphatic building Emphatic building	myMCS SB myMCS SB Locatee Locatee Locatee Comfy Comfy Comfy Fibaro	Thingsee Thingsee Yanzi Yanzi Comfy Comfy Comfy Enlighted Enlighted FIN FIN Go IoT Go IoT
Weather	SkySpark SkySpark SkySpark SkySpark		SMHI FC SMHI FC Leanheat Leanheat Fourdeg Fourdeg Netatmo E Netatmo E	OptiWatti OptiWatti Lerta Lerta	OptiWatti OptiWatti Lerta Lerta			

Fig. 2 Key functionality 1: multidimensional array for the readiness to facilitate maintenance and efficient operation

services and solutions included in this paper are around 3-4 digit for non-residential buildings, and 6-digit for residential buildings. It is safe to assume that summing up all the buildings that have at least one of the selected products, services or solutions reaches the order of magnitude of 7-digit, most likely somewhere between one and two million. Although, it might seem a lot in absolute value, it is almost negligible relative to the hundreds of millions of buildings across the globe.

The organisations offering the products, services and solutions are either incumbent ones from the building automation and facility management industry or new comers from the information and communication technology industry. There are successful partnerships or mergers between incumbents and new comers (good hardware needs good software), incumbents develop own software and enables IoT (on top of the common building automation communication protocol), new comers develop own hardware and integrates legacy hardware (in IoT).

The most noteworthy aspect of the current digital transformation is the intention of several market players, be they incumbent or new comers, to create IoT platforms that can integrate both legacy and new hardware.

Data science discipline →	*Statistics*	*Visualizations*	*Pattern recognition*	*Data mining*	*Machine learning*	*Artificial intelligence*
Aim of product, service or solution →	*Increase experience and satisfaction*	*Tenant management*	*Smart living and sustainability*	*Increase well-being, happiness and performance*	*IoT platform*	*...*
Data source ↓						
BACS / BMS	JEM MyMCS SB MyMCS SB Mapiq Mapiq bGrid bGrid BuildingiQ Comfy Comfy Comfy	JEM BuildingiQ		Tririga BI Tririga BI Tririga BI	Mapiq Mapiq Comfy Comfy Comfy FIN FIN	
IoT devices (humans included)	Indoors p Indoors m MyMCS SB MyMCS SB Locatee Locatee Locatee Steerpath Teem Mapiq Mapiq bGrid bGrid BuildingiQ Comfy Comfy Comfy	BuildingiQ	Leanheat Leanheat Watty Watty Optiwatti Optiwatti Fourdeg Fourdeg Fibaro Lerta Lerta SES Eve Netatmo E Netatmo E Netatmo W Netatmo A Healthbox Tado H Tado H Tado C Tado C	Emphatic building Emphatic building Comfy Comfy Comfy Ambinode Ambinode Ambinode Tririga BI Tririga BI Tririga BI	Thingsee Thingsee Yanzi Yanzi Mapiq Mapiq Comfy Comfy Comfy FIN FIN	
Weather			Leanheat Leanheat OptiWatti OptiWatti Fourdeg Fourdeg Lerta Lerta			

Fig. 3 Key functionality 2: multidimensional array for the readiness to adapt in response to occupant needs

When analysing the data science disciplines, visualization is ubiquitous in all the selected products, services and solutions. Most products, services and solutions additionally include data mining and several stand out from the rest incorporating a form of pattern recognition, machine learning and artificial intelligence.

The end-users are at the heart of the digital transformation which is attacking carefully and skilfully from different angles both the occupant and the building operator (facility manager). The products, services and solutions aim to make their life and tasks easier and more enjoyable while at the same time boosting business, reducing maintenance and energy costs, optimizing space usage or just enabling smart living. It is interesting to observe the trend of integrating all building services under one single umbrella (an app or a web interface).

Digital transformation is taking the digitalized way of using and operating a building to reach critical mass which will then push all products, services and solutions to reach economies of scale and eventually be cost-effectively incorporated in a few decades in all buildings around the globe.

5 Conclusions

The presented mapping could effortlessly serve as starting point for those interested in the topic of digital transformation of the built environment and provide a wider view for those active in the field. Although, the content is non-comprehensive, the aim was rather to develop an approach fully scalable to incorporate further data sources, aims of products, services and solutions and data science disciplines, which is most needed for these rapidly evolving offerings. The authors strongly believe it's fully feasible to integrate eventually all existing commercial activities available on the market at a given time if enough resources would be made available.

The authors endeavour to attract more colleagues to the process of continuously updating the mapping exercise and widening its reach. The underlying intentions are to establish a community on this topic that would connect the different market players, researchers and policy makers for facilitating further developments in the field of digital transformation in buildings and possibly start with supporting the development [11] and implementation of the SRI in Europe.

There is no doubt that digital transformation is reshaping the way we use and operate buildings, shifting from guess-based to complete evidence-based decisions stemming from the gained ability to bring from the invisible to the visible a breadth of information and furthermore analyse it and obtain actionable (automated) insights. What remains to be seen is if, how and who will be able to completely integrate all hardware and software under a single ecosystem and create full interoperability between all building technology enabling a single user-

building interaction interface, mitigating todays cognitive overload.

6 Acknowledgements

The authors would like to thank the conference organisers and reviewers for their patience and helpful suggestions for improvement during the submission process, as this is not the at all the ordinary conference paper.

At the same time the authors acknowledge the usefulness of having ease of access over the internet to information about products, services and solutions offered by front-running organisations facilitating the digital transformation of the built environment. A big thank you to all the transparent organisations out there!

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