A Mannheim Best Smart City Case: New Measuring System for the Complex Analysis of Spatially Distributed Environmental Data

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1 ABSTRACT

Serving Smart City (SC) and societal objectives (i.e. contributing to better air quality and combat the Corona virus), a novel measuring device is presented as the latest offspring of the SC Ecosystem Mannheim. In this paper – based on the description of the concerted activities of the various players of the Mannheim SC ecosystem – we aim to present the findings of our study of the distribution of gases and particles and their impact on the health of SC citizens of all ages and the ecological balance. Furthermore, the relationship between CO2 and liquid aerosols is discussed. In particular, the questions of how corona-relevant droplets spread and how quickly they evaporate are investigated. A broad portfolio of possible applications suggested by Nevoox rounds off the article. The practical case is interlinked with the results of the DevOps Competences for Smart Cities project with competences being the common denominator. The case reflects necessary transversal (such as creative, innovative, entrepreneurial, networking) and technical competences (i.e. related to coding, data architechture, big data, cloud computing or AI) to exist in an ecosystem aiming for sustainable innovation.

Keywords: health, ProxiCube, ecosystem, Smart City, DevOps

2 INTRODUCTION

The intensive SC engagement, positioning and branding of the City of Mannheim (Smart City Mission Statement 2030; Bitcom Award for Administration; Approved Role Model Project Smart Cities; future-proof city quarter development 'Franklin'; Urban thinker campuses) sets the stage for the product's current international success. The Mannheim Smart Production network is a nexus between manufacturing companies, research institutions and B2B solution providers. Here, the idea of the cube-shaped multi-sensor system was created during the development of the next generation of Industrie 4.0 manufacturing. Furthermore, the Wirtschaftsförderung Mannheim (Promotion of the Economy) provides know-how on location, real estate, financial promotion opportunities, recruitment of qualified staff or company contacts. Mafinex is Mannheim's technology center for startups. Last but not least Mannheim's universities propel the town's SC movement. The University of Mannheim scientifically accompanies the SC Model project and investigates, for example, the influence of SC on social imbalances. The University of Applied Management Studies Mannheim was a partner of the EU supported project on DevOps competences for SC having created the globally first MOOC program in this emerging knowledge stream. To provide some theoretical underpinning, this paper revisits two previous RealCorps Conference presentations on DevOps competences and Urban Management (Kaufmann et al., 2020; Kaufmann et al., 2021). Last but not least, the University of Applied Sciences Mannheim: the device development was led by Dr. Thomas Schäfer from the Institute CeMOS of the University of Applied Sciences Mannheim. The industrial production readiness of the final product was achieved by ProxiVision GmbH/Bensheim, and the responsible sales partner is Nevoox GmbH/Mannheim.

As a competitive advantage, the novel low cost device allows a much more structured and small scale environmental monitoring than was possible before its development and mass production. Suggestions for further research refer to the possibility to keep dozens of measuring cubes in operation in parallel. With this information, smart cities can be optimized by measuring environmental conditions in existing urban quarters or districts aiming to counteract detrimental consequences, thereby benefitting the health of the citizens of all ages and the ecological balance.

For this reason, the following experiments, application examples and possibilities focus on these aspects. Furthermore, the relationship between CO2 and liquid aerosols is discussed. In particular, the questions of how corona-relevant droplets spread and how quickly they evaporate are investigated.

3 MATERIAL AND MEASUREMENTS

The device, dubbed ProxiCube, is a cube-shaped multi-sensor system with an edge length of 8 cm (Fig 1), lead-developed by Dr. Thomas Schäfer from the CeMOS competence centre at Mannheim University of Applied Sciences. It measures distributed environmental data such as CO2, TVOC, temperature, pressure, humidity, luminous intensity, loudness, but also fine dust and liquid aerosols. More values, such as position, speed, acoustic frequency ranges, CO and much more can be provided as add-on sensors.

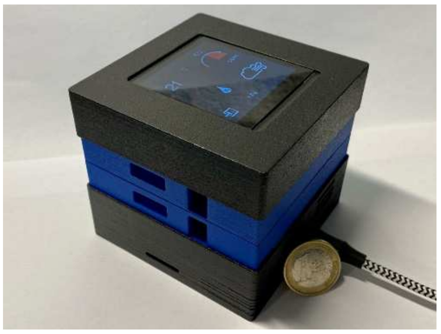

Fig. 1: ProxiCube NX3 series with digital display

All data are transmited to the cloud via radio can be retrieved, displayed, and further processed from the database worldwide via authorization certificates – also retroactively via mobile phone or PC or control centre.

Based on simultaneously measuring and storing all the aforementioned data via sensors, AI algorithms can be applied such as correlation clusters to be used for urban planning and management. The device categorizes dry particulate matter in different size classes and enables the exact identification of the respirable load and of the amount of dust trapped in the mouths and throats of citizens. The same applies to liquid aerosols, which are measured separately from dry particulate matter. Fluid droplets are also distinguished between respirable and non-respirable ones. As to liquid aerosol measurement, the standard integration of separately measured liquid aerosols which this environmental sensor makes this device worldwide unique. For the basic idea of the separate measurement of total aerosols and the liquid part, a patent has been applied for.

3.1 Outdoor and indoor air quality monitoring

The small and inexpensive sensor can generate the same measured values as highly complex reference devices as it was confirmed by recent publication (Westphal et al., 2021) and additional comparative measurements.

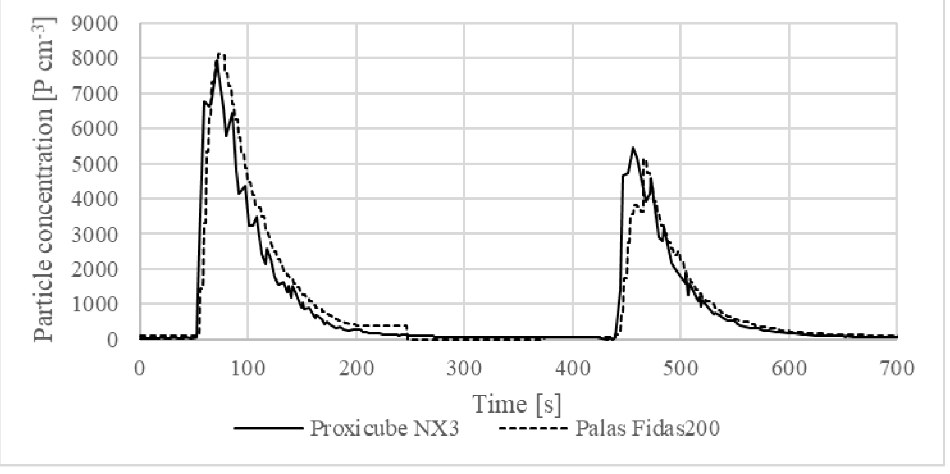

Fig. 2: Calibration of ProxiCube NX3 with Palas Fidas 200 with room dust

In Figure 2 the measurement of smoking candels in an exclosed chamber is shown. As you can see both Proxicube and the reference measurement device Fidas 200 show similar particulate matter concentration. Due to the inexpensive nature of the cube, for the first time, urban planners are now able to use a variety of measuring cubes not only to monitor particulate matter in a simplified way at neuralgic points in cities, but also to quantify its local distribution. They can, for example, investigate the question of how far the dust on the main road travels into the side streets, or up to which floor of a high-rise building it rises.

In addition to monitoring indoor air quality, the influence of outdoor air on indoor air quality can now also be studied and, based on this, measures to improve indoor air quality can be taken. To illustrate this, indoor air measurements were carried out in the kitchen of an institute.

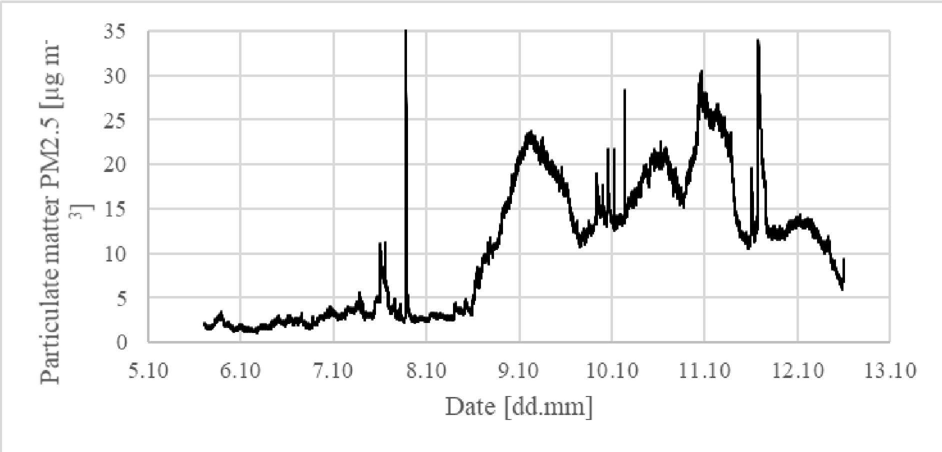

Fig. 3: Particle load in the kitchen of an institute (CeMOS, Mannheim, John Deere Str. 81A, diameter below 2,5 µm

Fig. 3 shows the respirable fraction (< 2.5 µm) of dry particles over the course of several days. In addition to short-term fluctuations, which can be attributed to the frequency of use of the kitchen, a connection with weather events and the resulting fluctuations in fine dust pollution can be identified (Fig. 4). At the start of the measurements it was raining outside. Therefore, the particulate matter concentration is relatively low. During the following dry days between 06.10.21 to 10.10.21, fine dust entered the kitchen through the open windows. This can be seen in the increasing background fine dust load. Towards the end of the measurements, it began to rain again. This is clearly shown by the falling fine dust loads. This makes it possible to localize the causes of fine dust and to initiate targeted countermeasures.

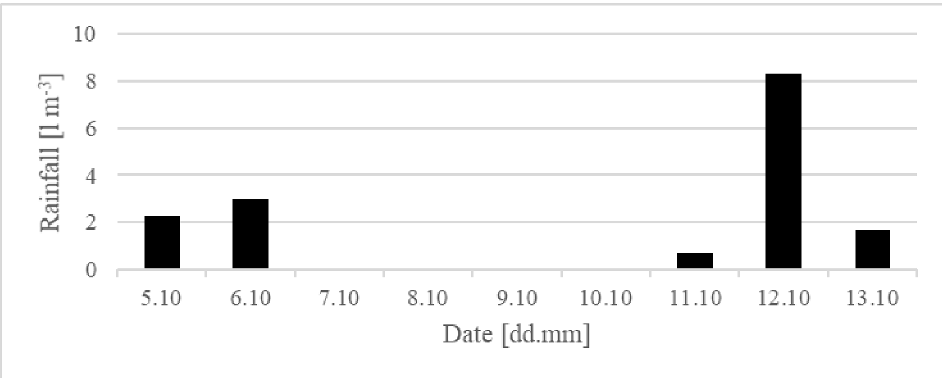

Fig. 4: Weather data recorded during the measurement period

In addition to monitoring particulate matter concentrations, the measurement of $CO_2$and TVOC shows correlations between various environmental impacts.

Figure 5 shows the increase and decrease of CO_2 and TVOC in the kitchen of an intitute during one working day. The institute's daily routine starts at 7am and ends at 6pm. Due to closed windows the CO_2concentration rises continuously until 6pm. There is a fairly obvious peak during lunchtime. The TVOC measured values show a similar behavior. There is a steep rise in TVOC level at the beginning, a peak during lunchtime and a steep fall at the end of the working day. Compared to the CO_2values, the TVOC value does not increase over time, but shows a relatively constant value.

One can also notice that the progression of organic air pollutants, which also have causes other than humans, is not fully correlated. The TVOC sensor in this case is non-specific and cannot distinguish between solvent vapors or outgassing of fresh rolls from the bakery. However, specific sensors are available and could be integrated if required by the city optimizer.

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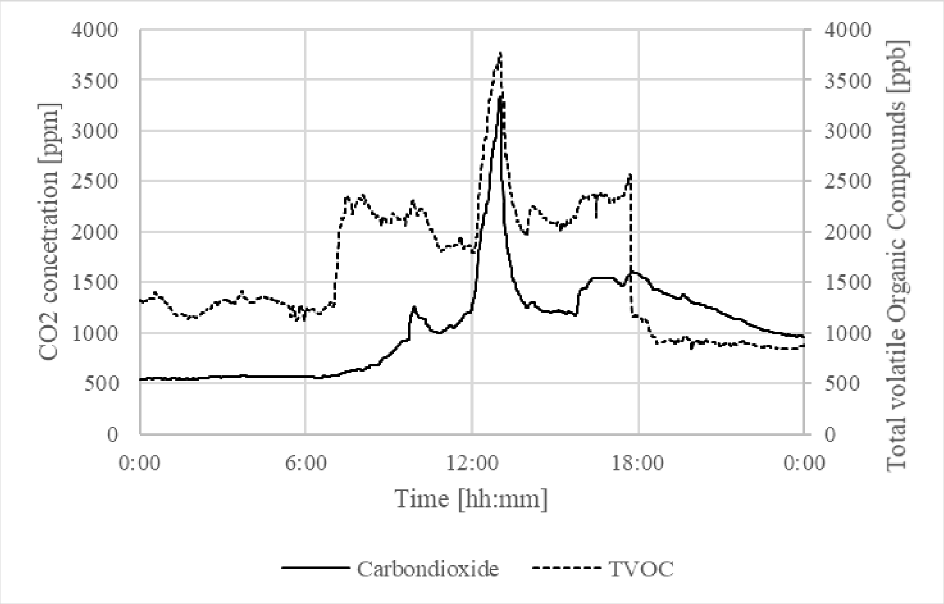

Fig. 5: Air quality measurement in an institute kitchen: CO_2 and TVOC concentrations

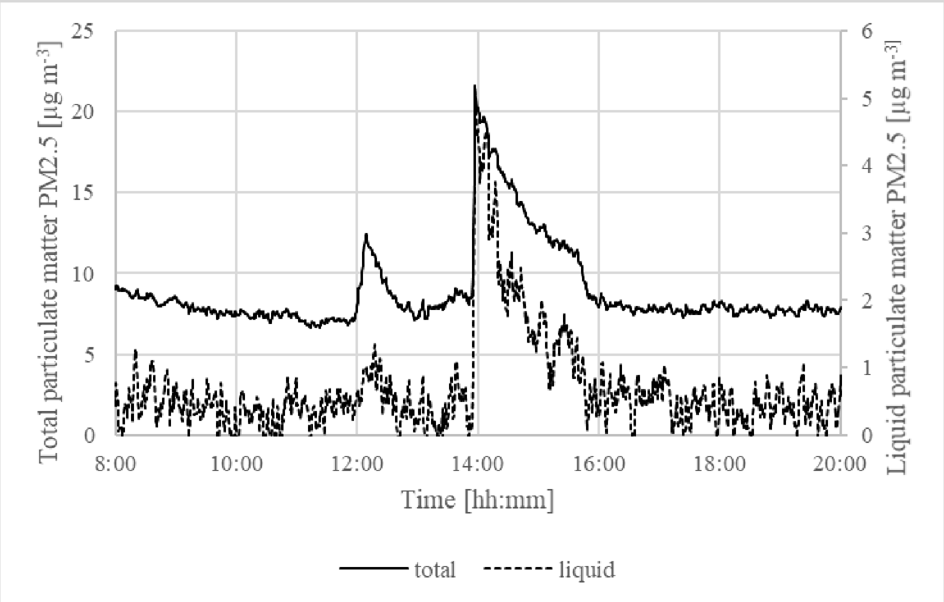

Fig. 6: Air quality control: fluid part of particles/droplets, < 2,5 µm

Figure 6 shows the course of particles in general (solid plus liquid) in one curve and in a second curve only the liquid droplets exhaled by humans during the same measurement as mentioned above. Both, solid particles (fine dust) and liquid droplets are correctly referred to as aerosols. The fraction of aerosols exhaled by humans should be referred to as liquid aerosols (Asbach et al., 2021). These liquid aerosols only occur when a minimum human exposure is exceeded. In well-ventilated rooms, no liquid aerosols can be found because they evaporate near instantaneously.

As it can be seen there are two distinctive peaks, for both general and liquid aerosols. The first, smaller peak during luchtime and a second bigger peak at 2pm. If we compare the course of the aerosols with the measurement curve for CO_2, we see that the aerosol load does not correlate directly with the CO_2curve. The high CO_2load during the lunch break corresponds to the lower aerosol load and vice versa. The reason for this could be that during the coffee break at 2 p.m. there were fewer people in the room than at lunchtime (thus less CO_2), but these people talked more to each other and thus more aerosols were produced. Overall, this suggests that measuring CO_2alone is not useful.

3.2 Examination of temporarily heavily polluted parts of buildings: Airlock in a public building

Another series of measurements shows values recorded over two hours in an entrance area of one of the main buildings on the campus of Mannheim University of Applied Sciences. The area is located between a door that opens to the outside and one that opens to the inside of the building.

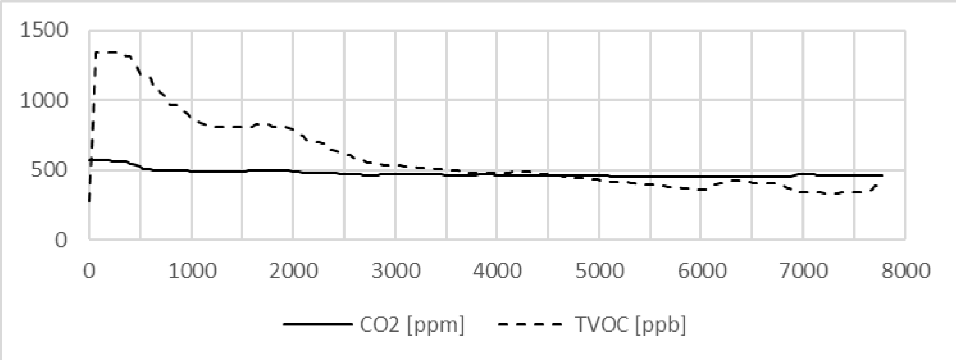

Fig. 8: CO_2 and TVOC measurement curves in the entrance area during the lunch break

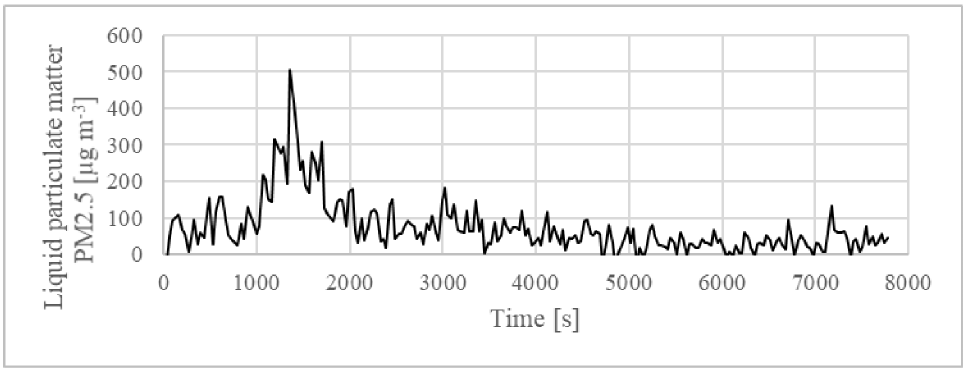

Fig. 9: Liquid particle measurement course in the entrance area during the lunch break

Approximately five minutes after the end of the lectures, an increase can be observed in both TVOC readings and particle readings as several students walk through the airlock (see figures 8 and 9). The CO_2 reading over the entire measurement period is 500 ppm due to the high frequency of door opening. The comparison of the measurement courses of CO_2, particle and TVOC measurements clearly shows that particle pollution lasting for several minutes does not correlate with CO_2 measurements.

3.3 Measurements compared to visualized fogging

A person enters a closed room with a volume of 7 m³ at the beginning of the measurement. After 20 minutes, the person exhales the smoke of an e-cigarette. The dissipation course of the exhaled cloud, a mixture of solid and liquid particles of different sizes and respiratory gases, is recorded as shown in Fig. 10 Within two seconds, the cloud passes over the measuring box in visible swirls and appears to become more transparent due to the distribution.

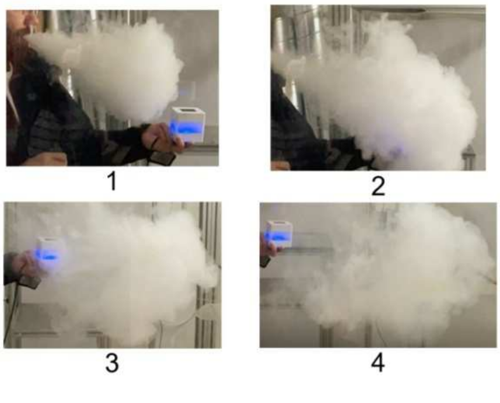

Fig. 10: Experiments in a closed room with e-cigarette: distribution of the cloud in the room.

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The first five vertical lines in Fig. 11 indicate the exhalation times. At the sixth line the person leaves the room and from the seventh line the ventilation is switched on. The NX3 sensor records a liquid particle count of 28601 per cm³, which corresponds to aerosol exhalation in the selected particle size. A CO2 concentration of 2105 ppm is displayed by this unit as a peak after 50 seconds (see figure 11).

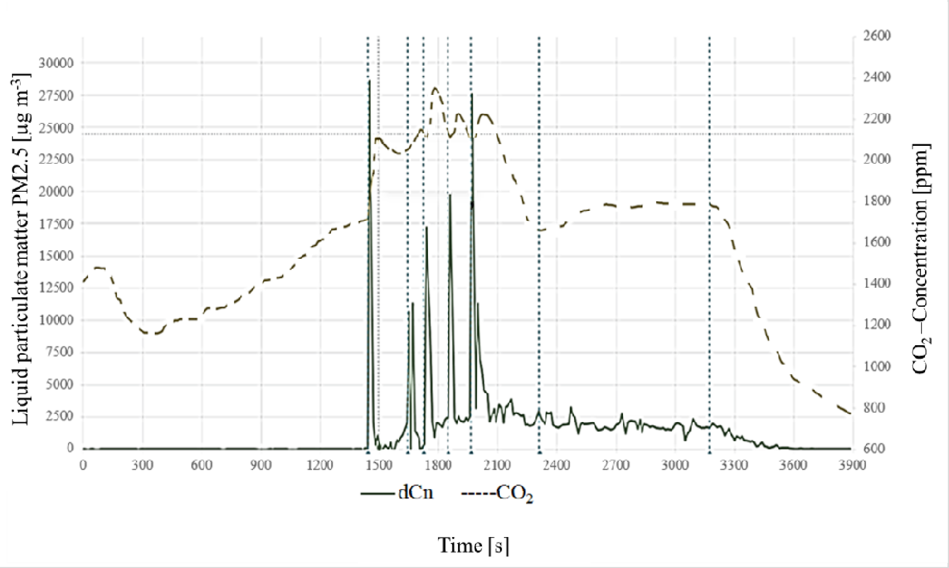


Fig. 11: Experiments in a closed room with e-cigarette: comparison of CO_2 and liquid particle readings directly at the source

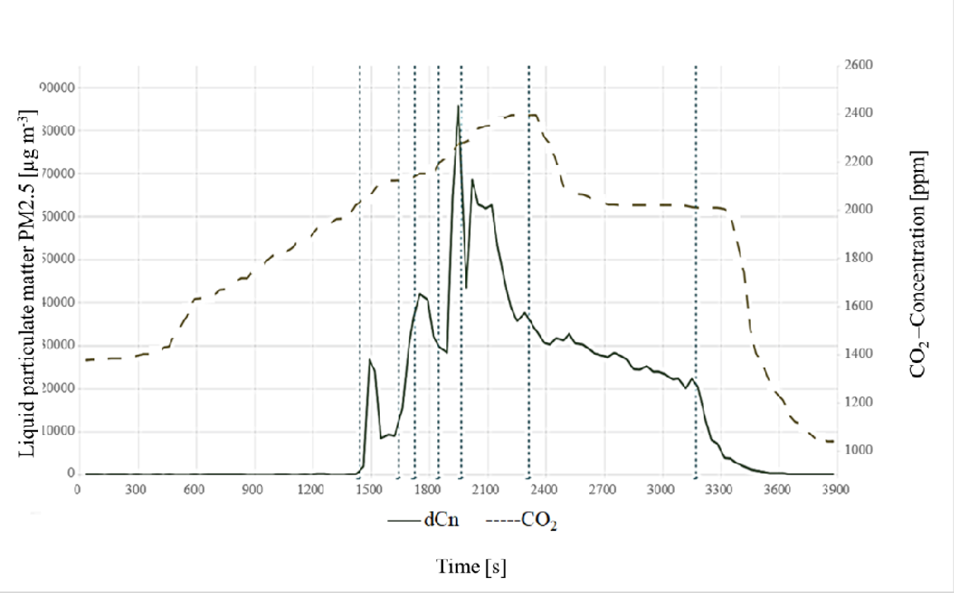


Fig. 12: Experiments in a closed room with e-cigarette: comparison of CO_2 and liquid particle readings approx. 2 m from the source

Another sensor is placed on the floor approx. 2 m away from the experimental setup (see figure 12). The peaks are only recognizable as individual peaks when looking at the dCn curves. Here, a CO_2 increase up to 2400 ppm is registered after the first exhalation. The aerosol measurement shows about 12000 liquid particles with a broader peak curve.

3.4 Current and future applications of the Cube

This highly precise patent-pending technology for indoor air quality and TVOC value measurement with wireless communication via WLAN, Matter, Bluetooth, LoRaWAN or more can be envisaged to be potentially useful for the following manifold settings (without being exclusive): offices and meeting rooms, restaurant and hotels, sports studios and clubs, private apartments and houses, medical practices, hospitals and clinics, nursing and old people homes, schools, kindergardens and day care centers, or hairdressing salons and cosmetic studios. The cube can be customized as to OEM’s requirements, colors, configurations or logos.

As already indicated, in the smart city context, this product is intended to be further developed for smart building management and smart homes further exploiting AI opportunities and networks such as Matter, an IP based communication standard, or the Definics or LON network technology. In this vein, future applications might utilize intelligent sensing needed, for example, for motion and presence detection, sleep monitoring (i.e. for babies and kids), or fall detection (i.e. elderly). In addition, relating to climate and pollution issues, and as stated before, urban planners can use a variety of measuring cubes in a simplified way at neuralgic points in cities and, additionally, can quantify its local distribution.

On retrospect, the sequential and diverse processes applied in this case might serve as a blueprint for urban management to initiate, plan and co-ordinate similar innovative cases in the future. The following section of the paper will show that this process of effective urban management requires to decide on desired and citizen driven SC ecosystem achievements and outcomes. On this basis, the priorities in relation with the conditional competences must be assessed and provided and, finally, implemented by an effective collaboration of all SC ecosystem stakeholders.

4 REVISITING THE DEVOPS COMPETENCES FOR SMART CITIES PROJECT IN RELATION TO THE CASE

This paper revisits previous REAL CORP conference presentations (Kaufmann et al. 2021 and Kaufmann et al., 2022) having provided the findings of the project ‚DevOps competences for Smart Cities‘ supported by ERASMUS + Sector Skills Alliances with the mission to support Smart City administrators as well as co-operating companies and partners in competence development. The project identified the core competences (digital, transferable, Smart City specific and DevOps specific) and future job profiles of city employees. The project’s methodology was based on a critical realist reseach philosopy and a triangulated qualitative and quantitative empirical research approach in four countries (Cyprus, Germany, Greece and Italy). A wideranging literature review and documentary analysis had been conducted as to elicit market demands and supply. The research was analysed using content analysis, as well as descriptive and explanatory methods such as cross tabulation, correlation analysis and PLS-SEM analysis. The project resulted in the first global MOOCs Course on DevOps competences for smart cities differentiated by administrative job profiles (smart city planners, IT heads, and IT officers). A sustainable network of International Best Practice was created.

4.1 Competences reflected by the cube case

This paper contributes to the discussion on the prioritization of technical, citizen and people driven Smart City philosophies. The cube applications refer to the people driven one due to focusing on health implications and their implicit solutions for citizens. It draws on the literature on data, technologies and infrastructure provided and points to the need for multidisciplinary literature in smart city themes exemplified by aerosol research in the SARS-CoV-2 context and by technical related literature to identify liquid and solid particles in ambient air. Developing intelligent measurement devices is certainly not the task of city administrators, but, due to the significant contributions of the cube applications to smart city objectives, the paper suggests enhanced understanding of the mutual competences required by all smart city ecosystem actors involved in a team based development approach. This is also underlined by that the data created by the measurement device will become part of the information decision support system of the smart city planner.

The integration of the paramount importance of measurement devices is suggested to be stressed and further integrated into longitudinal studies such as that of Tratz-Ryan and Finnerty, 2018, in Kaufmann et al., 2021) displaying the IT response to dynamic changes in Smart Cities via a Hype Cycle for Smart City Technologies and Solutions such as artificial general intelligence, smart building, data market place, city operation center, sustainability and COP21, smart monitoring for public infrastructures, IoT platform and Internet of Things, smart city framework, connected home, or intelligent building automation systems.

The experiment results of this paper support the qualitative findings of the project in that measurement devices might be regarded as the very basis to generate key success factors and competences for awarded smart cities (see figure 13): a smart city infrastructure and a strategy for digital transformation (see 3.2. in the following); as already mentioned, the findings of the experiments in this paper put the citizens in general and their health in particular at the centre of attention; the existence of necessary skills such as research, IT related, manufacturing and local and global marketing skills are confirmed as well as the implicit smart city education and knowledge transfer (i.e. from the research experiment laboratory to the schools and universites) to follow suit the market implementation of the product; last but not least, an idiosyncratic smart city identity positioning can be achieved exemplified by health orientation or innovation in this case.

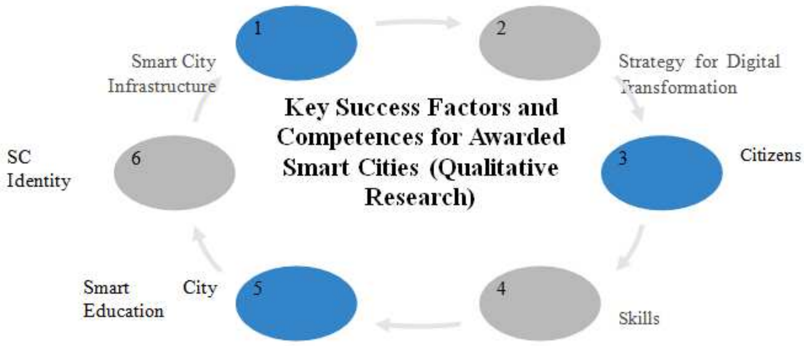


Fig. 13: Key Success Factors and Competences for Awarded Smart Cities (Qualitative Research)

Referring to the required typologies of DevOps competences for smart cities, this paper holds that - in terms of transversal skills - creativity, entrepreneurial thinking, the ability to work in a team, strategic vision & strategy development (including switching from operational to strategic competences, project and process management, design thinking, decision making, problem solving (& conflict solving), Leadership and Management Skills (including change management, new thinking), stakeholder management, sustainable development and advanced presentation skills have been required to develop and launch the product. All of these transversal competences have been confirmed unanimously by smart city planners, IT heads and IT officers to belong to the most important mandatory ones.

Referring to IT Management related competences the experiments provided in this paper confirm the relevance of knowledge on software development lifecycles, introduction to cloud computing and internet of things, system and software architechture, data analytics or risk management mandatory mainly for IT heads and to a lesser extent for smart city planners and IT officers.

Referring to smart city related competences, this paper confirms the relevance of smart city platforms, smart city business models, smart city operating procedures, smart city sustainability, smart city resilience, urban management, smart city services with a special focus on health due to corona crisis and citizen driven/citizen orientation/user experience design to be most important mandatory ones for smart city planners and IT heads.

Additionally, this cube case very well informs on the most needed competences in the field of responsibility of smart city planners as investigated by the DevOps project: Teamwork (i.e. regarding the nexus between research, manufacturing and marketing), urban innovation (i.e. reflected in the unique selling propositions of the cube in terms of reduced size and implicit scalability and private application and health movements as well as multi-sensoring features of the cube) and user experience (reflected, for example, in the readable display of the measurement for the users). With further and ongoing development of applications, this cube case provided might also give good practice insight into technical skills to switch from operational to strategic tasks, IoT specific knowledge as well as machine learning and deep learning, three competences in which the highest training demands exist according to the DevOps project‘s findings. In this wave, DevOps competences are highly recommended for further software development associated with the services of this cube, an additional high training demand assessed by the project.

Interestingly, the DevOps project revealed that the competences in which training is mostly needed, did not overlap with those competence developments for which co-operation with external partners is chosen such as mobile development, IT/cyber security or artificial intelligence. The project researchers concluded that these needed competences are rated as very important, so that these should be trained and be existent in-house instead of relying on external partners. This cube case, which was very much a teamwork success of several partners, however, either suggests to reflect on and revert this conviction or it might imply the perception that the members of the smart city ecosystem are not regarded as external partners by city administrators. However, external knowledge co-operation, most preferably- according to the DevOps project- with consultants and online and distance learning will still be required, especially in those competences in which fewer demands for training have been identified. The project revealed a strong positive and significant relationship between integrating DevOps competences into the own team and the co-operation with external DevOps teams with this co-operation having a strong adding value to cities in the future (indicating high perceived importance of DevOps and that DevOps competences in the own team (at least partially) is regarded a precondition for collaborating with external partners. Besides the already mentioned future potentially very successful cube application in the health service, this measurement device might have a crucial future role to play in smart building/smart home city services. The DevOps project elicited a significant relationship (0.01 level) between the competence perception in this field and its current and future importance for the city.

Based on the development of the cube case, the authors of this paper conclude to widen the perception of the ‚internal team‘ to a holistic smart city ecosystem represented by the quintable helix innovation framework (Kaufmann et al., 2022) with the five sub-systems of universities, industry, government (city administration), the public (citizens) and environment. Regarding the smart city movement, the cititzens are regarded the driving force. In the case of the City of Mannheim, the interaction of these ‚five players‘ is illustrated as follows.

4.2 Mannheim’s Smart City Ecosystem

The intensive global, European, national and local engagement, positioning and branding of the City of Mannheim sets the stage for the product’s current international success.

The Mannheim Smart Production network, initiated by the Mannheim Wirtschaftsförderung (economy promotion) in 2016 is a nexus between manufacturing companies, research institutions and B2B solution providers. Here, the idea for the basic shape of the cube was created during the development of the next generation of Industrie 4.0 manufacturing. The network is „Germany wide the only communally driven platform for digitalization of production. It unites ca. 50 innovative startups, Mittelstand companies, global players and scientific institutions from IT and production to a both, effective and efficient innnovation cluster in the Metropol- Region Rhine-Neckar and propels digitalisation in the region“ (translated from https://smartproduction.de).

Furthermore, the Wirtschaftsförderung Mannheim (Promotion of the Economy) aims to support Mannheim’s entrepreneurs to be successful and provides know-how on location, real estate, financial promotion opportunities, recruitment of qualified staff or company contacts (https://www.mannheim.de).

Being the home of more than 60 tech-orientated startups, the technology center Mafinex is a „hotspot of Innovation“ providing access to communication and exchange, a treasure of past experience, digital know how, and potential for possible co-operation and synergy between community management, startups and investors. In the meantime, more than 170 startups were successfully supported for their market entry (https://mafinex.next-mannheim.de).

The City of Mannheim positions itself as a digital, open, accessible and transparent City of the Future‘. In terms of digital administration, the Digital Association Bitcom awarded the city with the Smart City Award 2019 for the category of Digital Administration on the occasiom of the Smart Country Convention in Berlin. The award is based on the Smart City Index, a digital ranking of 81 big German cities.

In the Vision statement on ‚how we would like to live‘, emphasis is placed on putting the human being in the very center of ‚smart‘ and ‚sustainable‘ ideas developed together with and for all citizens, associations, public institutions, startups or traditional companies for a city which is worth living in. Digital and intelligently connected technologies shall be used to make life easier. Climate neutrality, resource efficiency, simplification of life and an ever stronger sense of community are the city’s objectives.

For the strategy development the city follows an overarching roadmap:

- Developing a Mission Statement 2030 ratified by the city’s council (Gemeinderat)
- Decision on the digititalization strategy with 40 measures and projects ratified by the city’s council
- Workshops with participants from central resorts, city-owned companies and communal enterprises
- Application and Award for the governmental program on model project Smart Cities

Together with other 31cities, the German government (Ministry of the Interior, Construction and Homeland, BMI) granted the model project called ‚sMArt roots (with MA being the city’s abbreviation) to the city. The model project‘s Smart Cities are promoted by KfW (Kreditanstalt für Wiederaufbau - credit institute for reconstruction). In addition, the BMI launched a co-ordination and transfer center consisting of DLR (Deutsches Zentrum für Luft- und Raumfahrt- German Aerospace Center-, Fraunhofer, Difu (Deutsches Institut für Urbanistik- German Institute for Urbanistics, Creative Climate Cities, Prognos and other partners, as a precondition to expand knowledge to a wider group of communities. The University of Mannheim scientifically accompanies the Smart City Model project and investigates, for example, the influence of Smart Cities on social imbalances. The focus of this project is to utilize digitization to improve life quality, upgrade public space, becoming more citizen centered and efficient, especially in the fields of energy, traffic and resources based on a validated, interconnected and sector transcending smart city strategy and agile processes. The results of this project should have a role modelling character.

- The sMArt City Mannheim GmbH (Society with limited liability) was founded, a Joint Venture of the city with the energy enterprise MVV Energy AG to expand on recycable energies, for example, based on a photovoltaic initiative aiming to make electricity consumption of city owned establishments totally climate neutral by 2027. The city has been selected by the EU mission 100 climate neutral cities by 2030.
- Finalising the Smart City strategy in September 2022
- Consultation and decision on the strategy in the main committee of the city’s council (Gemeinderat) in autumn 2022.
- Launching the Bundesgartenschau 23 (BUGA- National Garden Show) in Mannheim

The Smart strategy, furthermore, is informed by the results of the innovative open exchange platform for Urban Thinkers Campus, an initiative of the World Urban Campaign of the UN Habitat program aiming to promote sustainability in cities. Here, urban representatives and local and international experts provide input to societal developments on a global level. „To date, Mannheim ist the only German city to have organized this innovative format“ (https://www.mannheim.de). Since, 2016, this event takes place on a yearly re-occurring basis.

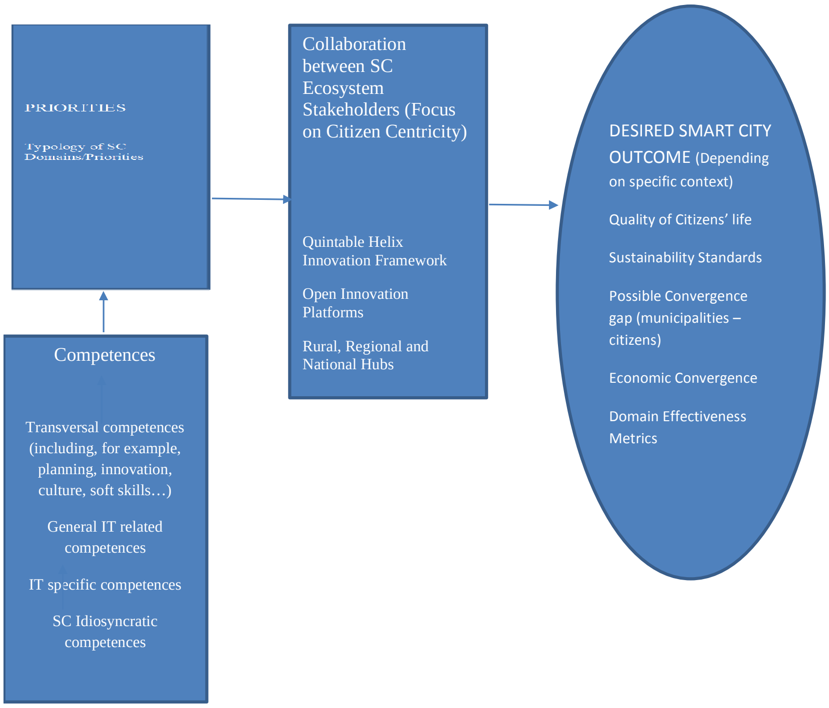
Both, social (socially mixed district) and ecological sustainability objectives are pursued by the development of the Franklin village, a future-proof city quarter to be completed by 2025, the former largest barracks site of the US Armed Forces in Germany, consisting of five largely mixed-used neighborhoods on an area of 94 ha (https://sdg21.eu). Existing buildings will be energetically renovated and new ones constructed entailing ca. 40% of the total area dedicated to a mostly green public open space. The mobility concept allocates equal importance to all transport users, and „public transport is complemented by innovative, low-emission mobility offers of the sharing economy (rental bike, rental car system, establishment and operation of an e-vehicle fleet“ (https://sdg21.eu). „In the Square project, GBG – Mannheimer Wohnungsbaugesellschaft - public utility housing enterprise- is developing two existing buildings into ecological model houses…The sustainability of the methods will be measured and compared by means of a 3-year monitoring of the measure after completion of construction“ (https//sdg21.eu).

Last but not least Mannheim’s universities propel the town’s Smart City movement. Besides the aforementioned involvement of the University of Mannheim in the ‚sMArt roots project‘, the contribution of other Mannheim universities, in particular that of the University of Applied Management Studies Mannheim, i.e. by developing the cube case at hand, and the University of Applied Management Studies Mannheim (HdWM) participating in the DevOps Competences for Smart Cities project have already been described before in detail.

5 CONCLUSION

Referring to the first part of the paper, the experiments confirm that a small and inexpensive sensor can generate the same measured values as highly complex reference devices in a more simplified and decentralized and even private manner. Besides the possible correlation between different environmental impacts, indoor conditions can be correlated with outdoor conditions enabling the design of targeted counteracting measures to improve the respective situation. The experiments showed that CO_2 measures should be supplemented by factors relating to human exposure and ventilation.

Referring to the second part of the paper, the described activities of the various stakeholders mirror the relevance of urban management model suggested in a previous paper (Kaufmann et al., 2022) in terms of the collaboration between the diverse players and the desired Smart City outcomes (see figure 14). The authors of this paper suggest to base the Smart City strategy on existing or newly created competences and increasingly on measurement devices, as this – as the DevOps project has shown- will determine the priorities and collaboration.



Source: developed from the authors based on Agbali et al. (2017) Allam (2019), Appio et al. (2019), Charalabidis et al. (2020), Cukusic et al. (2019), Garg, Mittal and Sharma (2017), Kaufmann et al. (2020), Lytras and Serban (2020), Ojasalo and Kauppinen (2016), Umar (2018)

Fig. 14: Urban Management Model

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