IAC-18-E1.9.14

CAPE (Climate Anticipation Personal Environment): Constructing the CAAS-Wardrobe

Sue Fairburn [a]*, Barbara Imhof [b], Jennifer Cunningham [c], and Susmita Mohanty [d]

[a] *Wilson School of Design, Kwantlen Polytechnic University, 5600 Kwantlen Street, Richmond BC Canada,* sue.fairburn@kpu.ca
[b] *LIQUIFER Systems Group, Vienna, Austria,* barbara.imhof@liquifer.com
[c] *Ma-tt-er, London, United Kingdom,* jennifer@ma-tt-er.org
[d] *Earth2Orbit Analytix, Bangalore, India,* susmita@earth2orbit.com
* Corresponding Author

Abstract

One of the greatest risks humanity faces is Climate Change. Evidence on sea-level rise and extreme weather events supports that climate systems are changing as well as our relationship to climate. Changes are taking place at the global and national level, on built structures at the city and community level, yet we construct an understanding of climate relative to our personal context. To anticipate future urban microclimate patterns we must find ways to imagine and communicate them, using indicators and modes that are more personally relevant and in real-time. A wardrobe is a personal and portable environment, a boundary between body and environment, with the capacity to sense and communicate as a climate indicator. We propose CAPE (Climate Anticipation Personal Environment) as an enhanced indicator, as a part of a wider project called City As A Spaceship (CAAS) that explores imminent spaceship parameters, such as climate monitoring and control, as important factors for crewed vehicles and habitats. CAAS is a metaphor for learning from reciprocities between a spaceship and dense cities - thus considering resource use, self-sufficiency, constrained spaces, renewable energy and multiculturalism; a spin-off and spin-in at the same time.

Data is pervasive yet invisible. Air quality is also difficult to see, yet it informs our beliefs that our environment is habitable. Consider a scenario where an individual wearing CAPE enters a courtroom holding proceedings on urban air quality. Once inside, the individual's wardrobe indicates the air is highly polluted. As perception is primarily visual, those looking around can now see the environmental contamination, as CAPE communicates the environmental status.

This paper introduces CAPE as a data-rich personal environment and an intelligent subsystem of CAAS in SMART city settings. It is a practical rather than an aesthetic wardrobe that integrates space technology beyond its original intent, capturing our surrounding environment - gaseous, thermal, and perhaps acoustic. It is a wardrobe that exchanges information between inhabitants and their urban habitats, where air quality, urban congestion, heat islands and extreme thermal fluctuations are an everyday experience. CAPE gathers data at the personal level and communicates with the commons. As the speed of Big Data processing approaches and exceeds the speed of living, it has the potential to be predictive and anticipatory and wardrobe becomes an indicator of urban microclimates.

Keywords: Wardrobe, Climate Change, Sensing, City, Spaceship.

Acronyms/Abbreviations

International Space Station (ISS)
ECLSS (Environmental Control and Life Support System)
CAAS (City As A Spaceship)

1. Introduction

At the Paris climate conference (COP21) in December 2015, 195 countries adopted the first-ever universal, legally binding global climate deal. While governments focus on policies and built structures, there is an opportunity for local and collaborative activities to drive local urban innovation and to construct an understanding of climate at a personal level. Data is a significant piece of the urban information that is shaped by patterns of human connection, comfort and contribution. Returning data to residents, data generated through their actions, we enable them to raise awareness and be more in sync with their daily patterns and environment.

To anticipate future urban microclimate patterns, we must find ways to imagine and communicate, using indicators and modes that are more personally relevant and accessible in real-time. To be alert, to react, to anticipate; these are the critical behaviours that influence the way people use things in different environments. We acknowledge that people are diverse, conditions are diverse, applications are diverse, and therefore this necessitates solutions that are relevant to diversity.

This work references and draws directly from a relevant project by the same authors; City As A Spaceship (CAAS): a metaphor for learning from architectural and design reciprocities between living on a spaceship and in extreme cities - thus considering recycling of resources (water, air), self-sufficiency, constrained spaces, renewable energy and multiculturalism; a spin-off and spin-in at the same time. In this paper, the CAAS themes and design-led approach provide a broadly framed concept for a wardrobe - Climate Anticipation Personal Environment (CAPE). At the core of this construction we consider Margaux Wililam's treatise on 'How to Dress in our New World' [1], specifically her final point:

> *'#24. We are not talking about comfort here, we are not advocating fleece. We must always be a little bit uncomfortable. We are, are we not, part of this world? We have to be alert here. We can't get too comfortable. As they say, if you are going to go anywhere, you mustn't get too comfortable.'*

CAPE addresses issues critically with a focus on wearable technology to monitor our discomfort with the environment on our home planet - Spaceship Earth. It proposes to draw from a 'data stew' of ambient information, satellite data, drone data, wearables data, and other ancillary data relevant to personal comfort to create a protective skin that communicates.

1.1 The City As A Spaceship

The challenges we face are global and demand considered actions, actions that may be provoked by visualizing the state of our current environment. This paper aims to raise consciousness and accelerate actions in our bureaucratized world, with an approach described in these key themes:

- Cities: Urban migration and increased densification are resulting in cities which operate at scales approaching country and state in terms of economy, control, power and politics. With increasing digital technology integrated into smart urban environments, the belief that logic, systems and order are central is countered by the realisation that people make cities and design should reflect their behaviours and patterns of use.
- Technology: While It is a tool to gather and analyze data to generate 'actionable intelligence' that can be used to make our cities more habitable and sustainable; it is also all pervasive and impacts privacy and allows manipulation of humans and society in dangerous ways. The advances made in Cloud Computing, Machine Learning (ML), Deep Learning, and Artificial Intelligence (AI) can be leveraged in creative ways for social and environmental well-being.
- Environment: This is a complex challenge with multiple offending activities, including; pollution, deforestation, landfills abundance, excessive construction, resource depletion, material permanence and people demanding greater access to limited resources.
- Society: With increasing migration, more inequality with a greater divide between rich and poor, and an aging population, the 'equilibrium' we used to know no longer exists. In its place are radicalized views that are challenging democracy and the notion of the civic harmony.

At the core of CAAS is a focus on the curation of the technological spin-offs from space design and how they could integrate into our daily lives. A spaceship in its' ideal state is a fully functioning biosphere where resources are carefully re-created; water and air are recycled and put back into the loop. An ideal spaceship is a technologized habitat that includes biological systems, leaves no trace, offers life-support systems in a fully closed-loop, and is powered by renewable energy. CAAS's approach focuses on the key themes of cities, technology, environment, and society – thus drawing the paradigm of spaceships – onto cities (Figure 1).

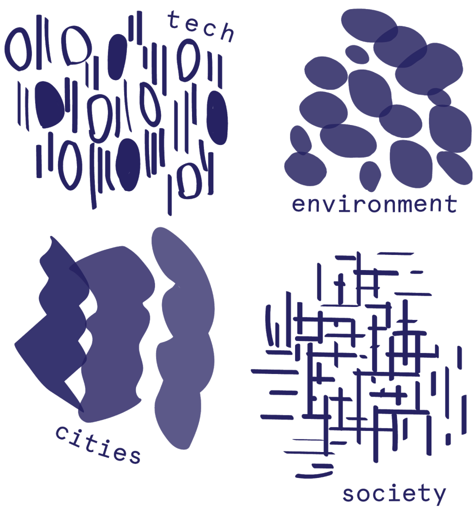

Figure. 1. Patterned gestures of City As A Spaceship (CAAS) (Credit J. Cunningham).

While science fact is central to CAAS, science fiction is often inherent in the work CAAS identifies and references alongside the former, and is visible in the creative outputs (figure 2). Critical theorist Donna Haraway [2] offers that the 'SF' acronym is comprised of many interweaving concepts, including speculative fabulation, science fact, science fiction, string figures and so far. The inclusion of science fact and speculative fabulation within the same SF figure allows the heuristic and factual to coalesce, a position relevant to CAAS and of interest to CAPE in its intention to enable the communication of big (quantitative) data alongside small (qualitative) data.

1.2 Climate Change and the City

In the wake of extreme temperatures affecting many cities in the Northern Hemisphere in summer 2018, Environmental Health Specialist Kathleen McLean, offered that *"people definitely become physiologically adapted to the temperatures in the place that they live in…"* [3] The context of this comment was whether there is a need to revise the public warning system.

Earth's climate is gradually warming and with the ongoing global migration trend, from rural to urban areas, climate change and cities pose a challenge to our future comfort and survival. In April 2017, the Mauna Loa Observatory recorded its first ever carbon dioxide reading in excess of 410 parts per million (ppm), an atmospheric condition that will cause greater heat trapping and an increased rate of climate change [4]. Climate Central, an independent organization of leading scientists and communicators of the impact of climate change, also note that Planet Earth has seen a run of 627 months in a row of above-normal heat, and the greatest climate impact is seen in cities. The evidence supports that the established warming trends, global and local, are likely to have a substantial and negative effect on the thermal comfort [5], health [6], and well-being of many urban dwellers.

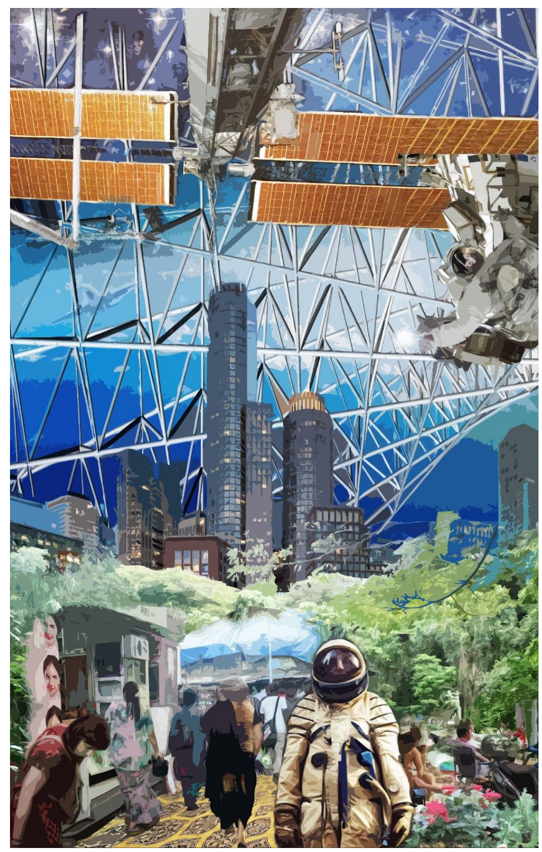

Fig. 2. CAAS Conceptual Collage of Earth Space Reciprocities (Credit B. Imhof).

Mills et al [7] argue there is a need to understand the relationships and links between global, regional and local climate and he stresses that the '*form and function of the city modifies the overlying atmosphere, creating a distinctive climate*.' One such local reference is urban heat islands (UHI); a distinctive climate that encompasses areas in the centers of cities, areas that are substantially warmer than the surrounding peri-urban area and countryside.

The impact of climate change in cities becomes more complex when air quality factors are added to urban heat complexes: heat accumulation, sun/shadow and wind effects. Climate scientists work to model and visualise certain climate characteristics, and their relationship to land use, and in doing so, they strive to access useful meteorological information to inform the placing of interventions. These interventions are conveyed through 'recommendation maps', a merging of climate science and urban design, sometimes called 'climatopes' [8], as shown in Figure 3.

Figure 3. A 'climatope' of climate-responsive recommendations merging climate science and urban design (Credit S. Lenzholzer)

Access to information at various scales is now publicly available through online mapping tools, such as Mapbox, a tool offering local and comparative global climate [9]. It offers climate projections for a given location, and for those locales with comparable climate. It also brings climate knowledge to the commons and enables urban residents to access information for specific interventions, such as 'cooling centers' in times of extreme heat, and warming shelters in times of extreme cold. This combination of linked information and interventions begins to empower citizens to access climate data in a manner enabling agency and comfort.

1.3 Big Data: Sensing (Remote and Personal):

The world is one giant dataset that includes us. We carry with us through the city – mobile phones, wireless nodes, computing power, and sensor platforms – which all generate data that we contribute to and consume. The Internet of Things (IoT) and a human are really not so different, as our bodies continuously scan, sense, process, and react – and most of the time we are unaware of this happening. We emit signals and we convey information to others. The urban environment is one part of this and it is the true 'cloud' that we inhabit as we move from locations, transit through spaces and navigate our surroundings.

The use of data in agriculture and healthcare is well established, as is the relevance to law, sociology, marketing, design, energy management, and all areas of natural and man-made sciences [10]. However remote sensing, monitoring and the Near Real Time (NRT) tracking and processing remain a challenge for all applications. For systems where response time is crucial, data must be processed in a timely manner, such as for the application of driverless cars – which use three-dimensional maps (known) alongside sensors that detect shapes and distinguish between a child on a bicycle and a plastic bottle rolling along a sidewalk (unknown). The challenge is in reacting appropriately to all problems posed by an ever-changing and unpredictable environment, that is, the unknown is becoming more complex and more unknown.

Big Data is characterised by volume, variety and velocity, the 3V's [11]. Veracity was added to reference the importance of the quality of the data collected, as accuracy and reliability are essential for statistical analysis. Data generated by sensors, society and sources is often unstructured and collected without experimental design or a research question – yet we are interested in the information to be gained from this 'stew of data'. The ability to search for patterns provides significant potential in the area of Big Data analytics. Further, with sentiment analysis we can go beyond samples to populations and address data with more complexity.

Holmes expanded the character of Big Data to include vulnerability, value and viability, and central to communication of information, is visualisation [10]. Visualising information is seen as a powerful method of supporting understanding, Tufte [12] comments: "we envision information in order to reason about, communicate, document and preserve that knowledge" and the recent emergence of the "infographic" as researchers and designers seek to make "Big Data" available to a larger population and decouple accessibility from privilege, indicates acceptance of the power of information visualisation [13]. CAAS explores interpretations of the 'city' as a 'spaceship' metaphor using graphical representations of information [14]. CAPE is also interested in the reciprocity of data, but between the population and the person, thereby aiming to make data more personal and personally relevant.

We are data obsessed and information compulsed – personal data drives our sense of understanding of self and informs our actions and wireless-enabled wearable technologies track our personal metrics. According to IBM, by 2020, medical data is expected to double every seventy-three days (p.68 [10]). With sensors worn, we monitor our bodies; our skin responses, our movements while we sleep, exercise, commute and work, and the beats of our heart. Sensors also monitor our position and our interactions with others and our environment.

Within a city context, we constantly share our observations of what we see, and what we do with others, and we make our location visible. We use the data to alert others to problems, such as traffic and the unexpected, such as dangerous routes. Equally, we alert others to opportunities; such as a preferred route (when cherry blossoms are in bloom), or an unexpected concert. Digital consultant Dan Hill offers this statement on the impact of digital technology at the city level and addresses the emergent opportunity for data to be collective yet relevant, spatially immersive yet mobile, expressive and on the person; *'…the way the street feels may soon be defined by what cannot be seen by the naked eye..the street is immersed in a twitching, pulsing cloud of data. This is over and above the well established electromagnetic radiation, crackles of static, radio waves…this is a new kind of data, collective and individual, aggregated and discrete, open and closed, constantly logging impossibly detailed patterns of behaviour. The behaviour of the street.'* [15]

Recognising this compulsion that drives us to consume more and more data, we realise the need to question the meaning of data. What are the scenarios we wish to identify that bring relevance to terrestrial data? How might we inform a connection with data, with data that is relevant to self and to others – that informs the connections essential to making data relevant - data that creates and supports the 'habitable smart city'? The SENSEable City Lab [16] is a project that embodies an architectural approach 'that senses and responds' – integrating Internet of Things (IoT) technologies into the built environment and into mobile platforms, such as urban vehicles; a data rich approach.

Messeri [17] questioned how "place" shapes scientific practice in her project called 'Placing outer space', which addresses the physical places occupied by researchers, and more importantly it considers the places they cognitively and culturally create. *"I emphasized the salience of place by positioning it as a product, not a precursor, of scientific work. The planetary scientists with whom I interacted gain a greater understanding of what they study by transforming planets from objects to places. I suggest that the methods they employ to do so - visualizing, inhabiting, mapping, and narrating - are prominent in planetary science precisely because they foster place-making.*

Data is used extensively as 'training data' to construct models for predicting future misses. The Statistician George Box wrote 'all models are wrong, but some are useful' [18]. It is not about exact representation of the world about us, as a good model serves as a good picture on which to base predictions and draw conclusion, but there is an opportunity for big data and science to work together, alongside society and design, to observe and acknowledge the patterns of society and suggest meaningful predictions of situations so that we are better prepared to survive.

1.4 Civic Climate; Wardrobes and Sensing the Commons

> *'The reliability of a piece of apparel as an environmental mediator is a measure of the relative uncertainty of the wearer and the climate itself.'* [19]

Clothing serves as the intermediary between our skin, our receptors and the external environment. While what we wear is an aesthetic choice, it is also informed by the immediate climate bubbles. Some choose textiles for a given a climate, those that reflect heat or are woven with fibres that ease air movement and facilitate evaporation. Others dress without regard for climate, instead sensing the environment and using data to inform their actions which when seeking a technologically modified space notifies them of the nearest air-conditioned coffee shop [20].

The version of future clothing shown in Fig 4.1 conveys clothing as provocation; as a ‘floating, automated comfort pod’ where the wearer is completely unencumbered. The pod allows them the ability to control their environmental temperature, activate tension relieving devices, and in the event of approaching hazards, float the user clear from danger [21]. The retrospective work of Archigram, specifically Michael Webb and two of his conceptual expressions also enables consideration of wardrobe as provocation. ‘*The Suitaloon*’ (figure 4.2) acts as apparel that reflects our experience and relationship to the climates we inhabit, and the ‘*Cushicle*’, as a mobile urban environmental device [22]. These expressions are wearables, proximal to the body’s skin and serve as enclosure; as a volume in which climate can be controlled and regulated. However, they serve as examples that are more of a spaceship than a city.

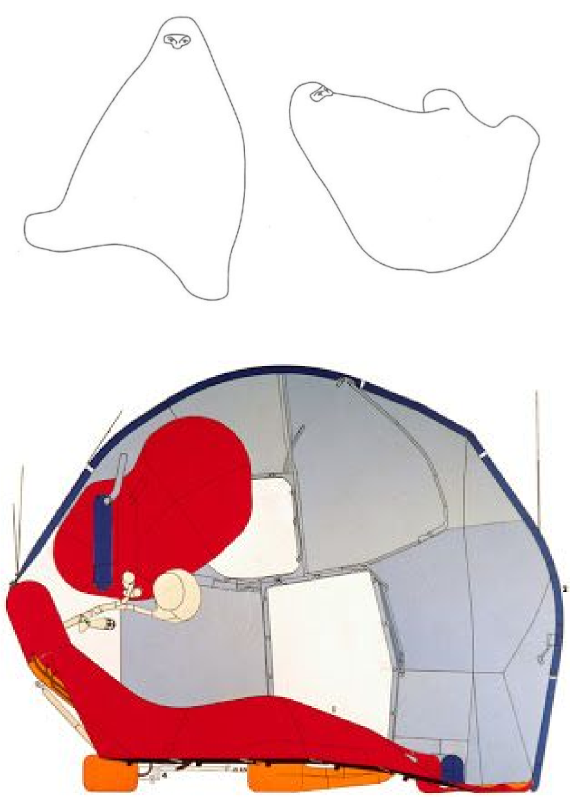

Fig 4.1 (top) and 4.2 (bottom). Clothing as provocation: a portable and protective environment (Body Covering, in Watkins Dunne 2015) and the ‘Suitaloon’ (Credit, Archigram).

We ‘make sense’ of our living and working spaces using a series of Wi-Fi-connected sensors to monitor environments through data, which can measure factors such as temperature, CO_2 concentration, and the status of rooms occupied and not occupied. The information sends instructions to products and services within the building – why? – for comfort, to reduce energy demands and because we can. This can contribute to individual or group-based ‘environmental bubbles’. The systems learn our daily routines and usage patterns, even preferences – so that the living and working spaces can be adapted accordingly over time. Data informs our wardrobe choices, our activity plans, and where to go and not to go in a city. As we consider data in the context of a wardrobe, what are the environmental sensor technologies that gather the data that are essential to survival in terrestrial and extra-terrestrial settings?

The “We Can” project shown in Fig. 5 proposes a visual narrative as a way of conveying data, mapping, and human activity and endeavours in the city [23]. There are innumerable cloud-based tools that aggregate data for the use of governments, industry, and entertainment. But there is a gap in how we understand the environment that our bodies are situated in and mediate through.

Figure. 5 Data Visualisation from the “We Can” project.

Hannah and Selin [19] propose that apparel offers the means to comprehend today’s environmental crisis. Their project ‘*A Year Without A Winter’* offers provocative visuals alongside a narrative that harnesses the scientific knowledge of climate change, in the hopes of motivating ‘adequate political, economic and technological responses’. Of interest, is their positioning of climate as a ‘lived abstraction'. While some reference the global concept of climate, they reference the ancient concept of 'Klima' and adopt the language of agency whereby climate 'refers to all the changes in the atmosphere which sensibly affect our organs' and influence 'the feelings and mental conditions of men.' Their approach extends the understanding of climate beyond the scientific reliance on data analysis and modeling to the need to understand the collaborative building of narrative alongside the individual capturing of data.

Forensic Architecture (FA) is a form of investigative practice which uses architecture as an optical device when looking further into state violence and human rights violations. FA utilises data gathered through new evidentiary methods that are both top-down as well as bottom-up [24]. Bricolages of audio, visual and textual reflections are gathered from social media platforms, satellite imagery, and materials sourced and leaked through hacks and recordings in order to weave together a post-real-time narrative. Their practice oscillates between critical reflections and calculated interventions. Of interest is their new forensis in which "civil society groups use a variety of scientific and aesthetic means coproduce and present evidence in the pursuit of public accountability" [ibid]. Big data and fabulations piece together narratives that have occurred in order to reveal the truth surrounding injustices within society.

1.5 Anticipation: Climate, Society and the Person

Anticipation, as recognised by the geographer Ben Anderson [25] is comprised by a series of styles - how futures spoken about in the present perpetuate how we think about them; practices - how futures are made present through modes of affect, thought objects and materiality and; logics - how futures are enacted in the present through methods of preemption, preparation and mitigation. Within anticipatory practice Anderson [ibid] argues it can be broken down into one of three categories : calculating futures, imagining futures or performing futures. These boundaries are less clear with those whose work is focussed on design forecasting and extrapolation practices.

Adams and colleagues write that "anticipation itself becomes the affective state that is lived and felt by those dwelling within this compressed and forecastable time, binding collectivities of nation, class or globe" [26]. Anticipation as practice, style and logic is acknowledged as an affective state of the present. It is a lived condition shared by societies. This survivalist state draws together notions of collective imagination and affect. By understanding imagination to be a knowledgeable condition, "a frame of mind that prepares someone to do something" [27], it takes on an active, affective role in the present. Affect can be considered from the perspective of the individual and society, and therefore so can imagination. Marina Garcés, in her article '*Honesty with the Real*', writes about the notion of being 'affective' which is in essence letting go of one's subjectivity [28]. It is then important to consider how a citizen becomes 'affective'.

In a recent interview Anab Jain, of speculative design studio Superflux, spoke of the importance of imagination in relation to their work [29]. This was not their own imagination but the imagination of those confronted by their works, which query the entangled landscapes of technology, culture, society and the environment. By materially articulating and probing collective thought individuals have the opportunity to critically rethink the world we may live in by reclaiming their imagination. Donna Haraway [2, 30] helps us to reframe what speculation could mean for design through one of the terms emergent from her idiosyncratic acronym - 'SF'. Speculative when used in conjunction with fabulation becomes more grounded. Fabulation is the making of fables hence fabulation is the making of worlds. Haraway used fabulation for two reasons, firstly because 'speculative narratives' are an existent critical literary genre and secondly due to its' everyday quality and she wanted to ensure the narrative aspect was tied to quotidian storytelling practices.

'Worlding' has been present in the developing iterations of Dunne and Raby's practice from critical design to speculative design and now as designed realities [31]. The narrative quality is fundamental in design work which aims to be mass communicated as opposed to mass produced. As forms of critical activism the work of Dunne and Raby, and Superflux use fact and fiction to anticipate what is to come.

Where anticipation is inherently tied to the present, speculation exists a little further from the now. Matt Ward argues that the speculative trajectory that design has followed needs to change and redirect itself along a route of care

[32]. Critiques surrounding speculative design argue about the accessibility of this narrative to the everyday person. Where speculative design tends towards provocations, dialogues of care enable design to be accessible and mobile through a humanitarian lens. With care at the focus, there is the ability for design to work in localised settings - where people are more than bystanders of the 'what-could-be' and instead actors in their possible worlds this is a position that informs and inspires CAPE.

2. Methodology

CAAS research serves as the platform from which CAPE emerged, and as such, the research methodology of CAAS informed the research methodology of CAPE.

2.1 CAAS Methodology

The CAAS methodology is immersed in the broad field of Design Research. According to Malika Bose [33], Associate Professor at the Penn State University, design processes are similar to a critical analysis as undergone in scientific work. It is this goal-oriented problem solving and the ability to channel information, which furthers the project or research question towards the theme and focus of the project. Additionally, it is about the evaluation of data through creative means. **Research by design**: taking design or case studies for research analysis□. **Design by research**: taking research results as a basis for design-oriented outputs. The CAAS design research approach involves locational scenarios and infographics, which are composed to deliver the analysis of the work, from which insights are drawn to add to the discourse within a given area, such as the design of environments.

2.2 CAPE Methodology

The CAPE methodology adopts aspects of the CAAS' methodology; research by design and design by research; and further informs the approach by assembling the 'SF acronym' of Donna Haraway with the framework of Forensic Architecture. This combination of conduits enables CAPE to consider the hidden systems, intangible fabulations and connections underpinning society and the environment in the everyday. As previously noted, fabulations enable speculation to critically express itself in the everyday, much like the science facts and patterns of data which are in a constant flux of change. Forensic Architecture gathers fragments of data from disparate sources assembling tales and truths from evidence that tie together in its patterns. As Forensic Architecture reveals injustices within society CAPE hopes to elucidate injustices within climate. Where we use climate as the analytic device, they use architecture.

The presentation of 'data' is demonstrated through visuals, and provocations, both in raw image, enhanced through experiences of inhabiting and narrating (figure 6). Alongside this is the creation of operative models that not only represent but also 'do things'. Spatial and non-spatial models provide a theoretical framework to what may have happened as well as having the capacity to be predictive. In order to be effective and affective they need to be calibrated with the physical phenomena they wish to represent; this is the aim of CAPE, not only to recognise but also to act, react and 'affect' without the prophetic qualities inherent to predictions. Just as Forensic Architecture claims to be a form of "architectural intelligence" CAPE is a form of "material intelligence" similarly grounded in an evidence based approach.

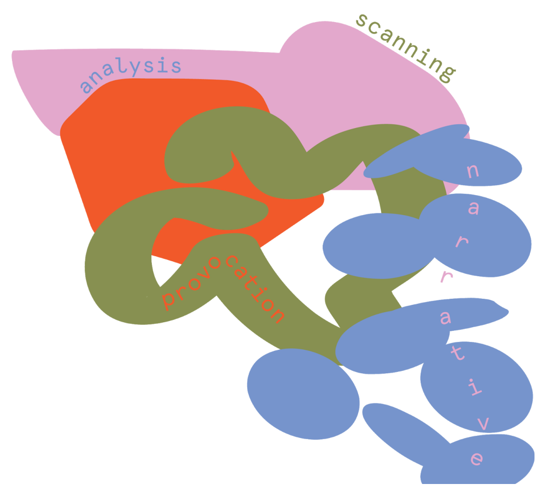

Fig.6. The stages of CAPE design research methodology (credit Jennifer Cunningham)

The CAPE evidence base includes a curated set of four case studies. Figure 7 is a visual representation of the case studies using the CAAS patterned gestures of cities, technology, environment, and society, as previously seen (Figure 1). They were selected, analysed and are presented in an order moving from *contained, low-cost monitoring technology* (3.1), to technology that expands into the environment for *citizen-sensing* (3.2) and *earth observation* (3.3), leading to technology that integrates into the environment and society in extra-terrestrial settings (3.4).

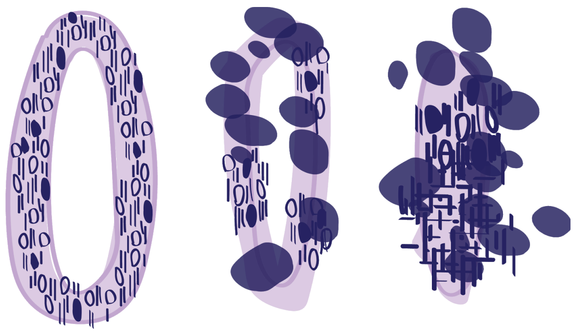

Fig. 7. Visual representation of the CAPE case studies progressing from contained technology and (left) across to technology integrated and exchanging with the environment and societies (right). (credit Jennifer Cunningham)

3. Case Studies

The four case studies progress through the considerations of **scale, data, application** and **relevance**. In referencing scale, each case study was analyzed for its' setting and geography (i.e. person, building, neighbourhood, city, region, country, planet). With regards to data, the focus was on the complexity and the integrity of the source data; the types of key data and ancillary data; and the transmission, collection, and analysis of these data. The application and accessibility of the data addresses how the information is presented - whether in raw format, visual, or narrative. Lastly, there is the factor of relevance, which is included to convey whether the intervention outlined in the case study is of private or public relevance i.e. whether it is of benefit to organisations, to society, or to an individual.

3.1 Personal and wearable 'low-tech' monitoring in urban environments - Air Quality in New Delhi.

Air quality in New Delhi is consistently found to be in the severe/severe plus category. Government findings indicate that prolonged exposure to the level of pollution is hazardous even for healthy persons, and especially for children [34].

This case study was drawn from an interview with S. Sambyal and S. Mudgal, Senior Research Associates from the Centre for Science and Environment (CSE), a New Delhi based non-profit think tank for environmental research and advocacy [35].

Scale: A group of citizens were assigned to each carry a portable monitoring machine for 24 hours to assess each person's exposure to real-time pollution in relation to the background ambient levels monitored by the Delhi Pollution Control monitoring stations. To capture data on air pollution at the building, neighbourhood, and city-scale, a CSE Research Associate wore one of the machines in a backpack while commuting in New Delhi (Rohini to Vayusenabad); *"I carried it from here, in Delhi, to my home in Rohini, which is about 40 km away...through the metro, through the bus stations, through a car, through a car with and without air conditioning... just trying to experiment and trying to peek into that bag again and again to see what is my exposure to Particulate Matter (PM) 2.5 and 2.10 or basically air pollution."* [ibid] As part of the same intervention, the backpack was also worn into a Delhi courtroom during a hearing on an air pollution monitoring case.

Data: THe CSE backpack contained state-of-the-art instrumentation - a TSI DustTrak DRX Aerosol Monitor 8533 system designed to simultaneously measure PM1, PM2.5 and PM2.10. The monitor was portable, battery-powered, and carried in a padded backpack to minimise instrument tilt and vibration. Data-logging included real-time aerosol mass readings in the immediate environment of the sensors [36]. There was no ancillary data. The data wasn't transmitted and therefore it was a unique, real-time monitoring exercise.

Application and accessibility of information: In the high court setting, the data was processed and displayed in real time for the purpose of provocation, evidence and advocacy. The impact of the visible data intervention was immediate; *"...the high court judges were baffled when they realised that even the air they are breathing in the courtroom is also highly polluted... Now they are like 'we want to live in a bubble and we want at least some kind of air pollution control systems installed for the courtroom.'* [35]

The cumulative data from the 24-hour commuting exercise was processed and visualised with corresponding transportation modes (Figure 8) to illustrate particulate matter levels versus background ambient levels over the course of a a 24-hour day. The information is publically available in a report on CSE's website.

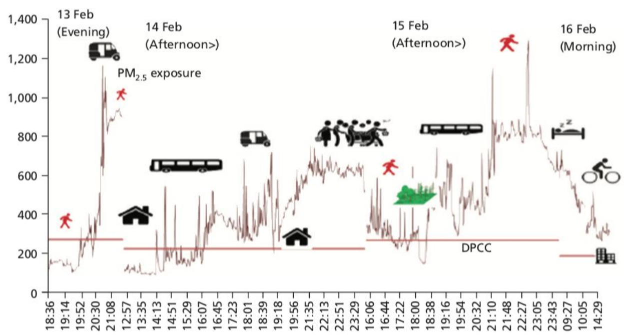

Fig. 8. Exposure to Particulate Matter (PM) PM2.5 by Travel mode vis a vis background ambient levels (Image Credit: CSE, 2016)

Private or Public Relevance: The outcomes of this air quality research were published as a white paper and informed policy as a result of a November 2016 Supreme Court hearing [36]. This research now informs public information systems through a practice whereby daily air quality is based on the Air Quality Index (AQI) and relevant health advisories.

3.2 "Who makes decisions about the quality of air we breathe?" - Citizen Sensing through Luftdaten

'Luftdaten' is an open source data platform that crowd-sources information for the comparison of changes in environmental factors [37]. The platform consists of a series of stationary, self-built sensors which communicate with a central database tracking and visualising real-time data about the surrounding air quality. Data transmitted by individual air quality monitors (AQM) continuously update the online Luftdaten map. Hexagonal shapes overlay a map of the world; their shade a visual representation of the surrounding particulate matter, enabling individuals to see their changing levels across time and space.

Scale: The focus of Luftdaten is local and city scale, though the initiative is also spreading globally. It began from the realisation that a local station presented the highest measured concentrations of particulate matter pollutants. Just as this observation in Germany provoked citizens to query their surrounding environment, controversial plans to erect an incinerator in northeast Scotland led a local to query "*who makes decisions about the quality of air we breathe?*" This provoked her to initiate a DIY air quality workshop held at a nearby public library. The group was comprised of individuals concerned about the environment, interested in citizen science and the real-life application of data, and general hobbyists. Although available to witness on a global scale, the individual wants behind this hyper-localised data collection vary from person to person, emphasising the potential of Luftdaten within citizen science. As an open-source platform the uptake of the system is happening at various scales globally.

Within urban and rural centres the sensors are built and maintained by citizens, hence differing rates in adoption. In areas with multiple sensors it is possible to compare levels of PM and Nitrogen Oxide (NOx) depending on the scale at which you view the map. Each device has an identity which is linked to the location it has been registered at by its owner, and if it is moved individuals are expected to notify Luftdaten so the map can be updated. There is the capacity to programme the device to pick up incorrect signals, thus making the data and corresponding visuals inaccurate. Device hacking in areas with few air quality monitors could affect people's perceptions of their surrounding environments and this could be utilised as a tactic to disempower action.

Data: Lufdaten began as a citizen science project which aimed to make the data about our surrounding environment (such as temperature, relative humidity and air pollution) visible and accessible to the wider public. Luftdaten intended to provide a visual measurement of air quality, recognise the effect of high traffic volume on surrounding air, and track the exposure of particulate matter and nitrogen oxide in residential areas through map based visualisations of the most recent measurements.

Users can decide whether their Air Quality Monitor (AQM) collects the data of particulate matter, or that of NOx. Data is translated into graphs which track the levels of PM10, PM2.5 and NOx over the past 24 hours. This is enabled by three component boards, SDS011 Fine Dust Sensor and DHT22, Temperature and Humidity - which are protected by an outside casing. Users are encouraged to collaboratively modify and improve upon Luftdaten software through their Github [38].

Application and Accessibility of information: Through multiple devices, citizens and cities are able to see what is happening and what has happened in their surroundings (figure 9). The question then arises - *once the visualised data has been processed by an* *individual, at what point do they act?* Since the workshop only a handful of the completed devices are visible on the map. This negligence questions the suggested simplicity of installation and the reality that people would have to acquire the parts, prepare the materials and code the boards before assembling and installing the AQM. The build and installation of the monitors is the first step to enabling individuals to understand their surrounding climate through Luftdaten's online visualisations, but the individual is still required to act.

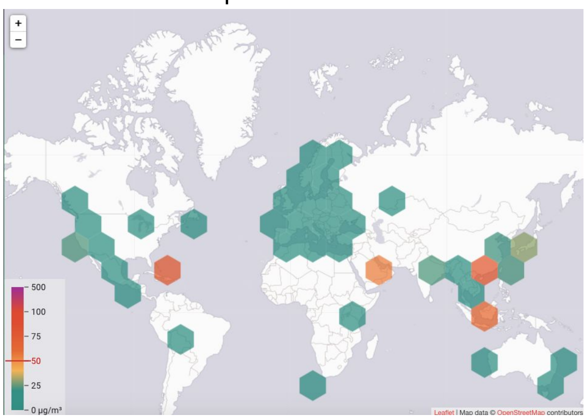

Figure 9. 'Luftdaten' open source data platform screenshot showing distribution of sensors. (Image source Luftdaten, 2018)

Private or Public Relevance: Even though citizen-built, the information gathered reflects only the building. The current stationary aspect ties data to place and not person. Luftdaten's objectives are to gather air quality data on-the-go through the development of a mobile solution for simultaneously visualising individualised routes on the map; a form of personalised air quality tracking. To enhance the system Luften wish to allow public entry and grading of symptoms common to areas with high levels of PM and NOx. The documentation of coughing, wheezing, sneezing and itchy eyes contributes to a "*geographic mapping of symptom frequency and intensity"*. This link between personal health and mobility, while comparable to health wearables, the critical difference Luftdaten offers is that the shared map created enables a collective knowledge of the surroundings. Luftdaten is for the people and not just for the person.

3.3: Earth Observation (EO): the Big Data and Global applications of C40 and E2O

There are many examples of larger scale initiatives that approximate earth observation. Two examples of such initiatives are C40, a city collective out of London who act globally, and Earth2Orbit Analytix (E2O), a Bangalore-based Earth Observation (EO) analytics company. Both initiatives are driven by Big Data and global applications. This case study is drawn from E2O's operating model and a recent C40 event held in Bangalore in July 2018 where 14 cities from the C40 Air Quality Network participated, including London [39].

Scale: Operating at the city and regional level, E2O is developing predictive analytics models for applications at various scales which relate to urban air quality and habitability, agriculture, water security, renewable energy, and insurance. Use cases range from estimating crop acreage, to mapping urban heat islands or tree cover for cities, and identifying viable rooftops for solar power harvesting or rooftop horticulture.

During a panel discussion at the C40 Bangalore event, where E2O was also in attendance, Elliot Treharne, Air Quality Manager at the Mayor of London's Office said in addition to the traditional ground stations, his city is debating whether to gather air quality data from mobile sensors, inexpensive ground sensors and wearables in the near future [ibid]. London, in partnership with C40, plans to trial a new £750,000 cutting-edge street-by-street sensor air quality monitoring system which will be used to analyse harmful pollution in up to 1,000 toxic hot spots across the city including schools, hospitals, construction sites and busy roads. Such Near Real Time (NRT), high-resolution "change detection" at a city or continental scale can also be applied at a hyperlocal or individual scale.

Data: E2O combines EO data (from satellites, such as Landsat, Sentinel, Cartosat, Resourcesat, etc.) with other relevant data to deliver actionable intelligence for social, business and environmental impact. The most common air pollutants include COx, NOx, SO2, ground-level ozone (O3), lead and particulate matter (PM10 and PM2.5). Primary data sources for air pollution monitoring are fixed ground stations with automatic equipment at breathing height that take readings every 15 minutes. As per the 2016 London Air Quality Network (LAQN) annual report [40], the network consisted of: 67 stations that monitor NO2 data, 14 stations that monitor PM2.5, 53 that stations capture PM10 data, 5 sites that monitor SO2, and 18 sites that monitor Ozone (mostly placed in rural areas as

NO2 skews the readings of other pollutants in urban areas).

Application and Accessibility of climatic information: To implement regulatory measures and raise public awareness, accurate real-time air quality monitoring at high granularity is needed. Conventional methods calculate Air Quality Index (AQI) at an Area of Interest (AOI) by interpolating the measurements from fixed ground stations. With the C40 system, the pollutants being monitored can be displayed on a map that can be viewed by entering a postcode. Satellite data can complement this method.

In the past, data from a NASA satellite - Moderate Resolution Imaging Spectroradiometer (MODIS) - was used to map air pollution [41]. However MODIS' low spatial resolution (3 km) only delivers insights, not actionable intelligence. In response to this limitation, E2O, is proposing a hybrid solution that uses composite satellite data from 3 different satellites - INSAT-3D (Indian), MODIS (American), and Sentinel (European) to improve the temporal and spatial resolutions of AQI. The solution includes a Machine Learning (ML) model that will use Aerosol Optical Depth (AOD) data from these satellites combined with weather data to monitor particulate matter. This model will be calibrated using particulate matter data from ground stations: the result would be high resolution actionable intelligence on air quality.

Private or Public Relevance: Air pollution has direct implications for public health and productivity, and the particulate matter is visible. (figure 10).

Fig. 10. Accumulated particulate matter on Delhi foliage in Khirkee village. (Credit: S Fairburn)

In the case of India, where 1.3 Billion people reside, the urban air pollution quality indicators growth rate is alarming. India has 14 of the top 20 most polluting cities in the world. A recent study [42] revealed that air pollution was a significant contributor to 80,665 premature deaths of adults aged over 30 years in Mumbai and Delhi in 2015. In economic terms, air pollution cost the two cities US$ 10.66 billion in 2015 or about 0.71% of the country's gross domestic product.

Results from London's C40 air quality sensor monitoring trial will be used to better target policies, and to engage citizens, and this approach will be shared with Bengaluru and other cities in the new C40 Air Quality Network.

A new global study [43] confirmed a link between diabetes and air pollution (PM2.5) and estimated that 14% of all diabetes cases in the world in 2016 can be attributed to air pollution. With the study aggregating past global research on diabetes and air pollution, it devised a model to estimate diabetes risk based on the level of pollution. Using the Global Burden of Disease study, it found that 8.2 million years of healthy life were lost globally in 2016 to pollution-linked diabetes. There is an urgent need for city level air pollution monitoring and this will require a cloud of shared data from ground stations, satellites and mobile devices including wearables.

3.4 Extraterrestrial Data sensing and monitoring: the person and their environment in Space

Humans are fragile creatures and in relation to some extremophile microbes. We can only live in a very narrow defined environment, within a precisely defined quality of air, and range of temperature and atmospheric pressure. We need oxygen (O_2) which only makes 20% of our terrestrial atmosphere and we release carbon dioxide that fuels Earth's plant life. To sustain human life outside the Earth's atmosphere, Earth conditions need to be replicated, and for this there are extensive controls in place on the ISS and in personal space suits. These systems not only exemplify telemetry and technology that integrates into the environment and society in extra-terrestrial settings but are also of significant relevance to future terrestrial settings.

Scale: As intelligent environments, they are building, neighbourhood, region, city, country and planet all contained in one. The scale of living is intelligent, closely monitored and highly controlled. As a pressurized living environment, the ISS operates under normal air pressure (101.3 kPa = 14.7 psi); the same as at sea level on Earth, thereby mimicking an Earthly environment as a shared habitat and a wearable environment [44]. The ISS has monitors and sensors for O_2, partial O_2 pressure, Carbon Dioxide (CO_2), radiation, microbial and fungal bacterial growth (per manual swiping), volatile organic compounds, humidity, temperature and noise. Figure 11 illustrates the on-orbit Environmental Control and Life Support System (ECLSS), a complex set of technologies and equipment necessary to maintain life within a spacecraft such as the ISS or for surface habitats.

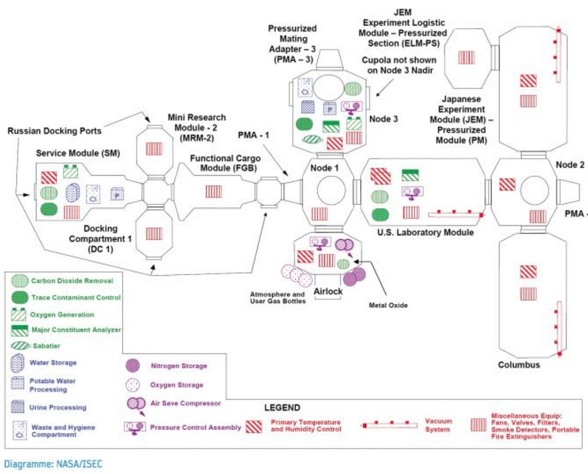

Figure 11. On-Orbit ISS ECLSS Hardware Distribution as of February 2010 (Images: Courtesy of NASA).

At human scale, spacesuits represent a tight-fitting biosphere, a microclimate around a human body exposed to the very extreme environment of space (temperature and pressure extremes). While different suits are designed to address different environmental contexts: Extra-Vehicular Activity (EVA), Intra-Vehicular Activity (IVA), Surface, and Zero-g, each suit houses a Portable Life Support System (PLSS) providing a pressure environment, oxygen, a mediate temperature (cooling), water and a possibility to release liquids [45]. The Extra Mobility Unit (EMU) space suit (Figure 12) used for spacewalks, allows the astronaut to manually control their internal environment and to sustain their basic physiological needs through the PLSS, in addition to containing extensive telemetry that is monitored remotely.

Data: To ensure the safety and habitability of the ISS volume, the environmental data monitoring is continuous and data collection is constantly streamed, in situ and remotely to Mission Control (i.e. not public). For example, a variety of O_2 sensors are in place: including two units containing twelve amperometric O_2 sensors in the Flux Probe Experiment (FIPEX) experiment [46] a specific Oxygen Control System (OCS) in the Electromagnetic Levitator (EML) facility and multi-gas analysers distributed throughout the station. Overall, the so-called Air Contamination Control (ACC) sits within the ECLSS and monitors the concentration of trace contaminants from the cabin air that controls partial pressures of O_2, CO_2, hydrogen, methane, nitrogen and water vapour [44].

Figure 12. Astronaut Sunita Williams in the EMU space suit (without helmet) (Credit Robert Markowitz)

There is a loss of natural convection on the ISS, due to the unique microgravity environment, therefore artificial ventilation is needed to avoid harmful CO_2 pockets that can occur when astronauts breathe out. Since the atmospheric environment on ISS is fragile, CO_2 sensors are everywhere in the station and even integrated into clothing [47]. ISS cabin air velocity is maintained at 10 to 40 feet per minute with a relative humidity of about 60%. As a semi-closed loop system, the ECLSS reclaims water vapour and sweat, but it requires High Efficiency

Particulate Air (HEPA) filters to keep harmful vapours out of the breathing atmosphere.

Microbial growth, both bacterial and fungal, are found in space habitats and transports, especially where the extreme external temperature changes meet the surface of the modules, therefore systems such as E-Nose [46], a portable sensor system which is able to detect in situ bio-contamination, are essential. Airborne potentially harmful volatile organic compounds (VOC) (i.e., ethanol, methanol and 2-propanol) are also monitored and analyzed using a gas chromatograph and ion mobility spectrometer [48]. Thermally, the ISS environment offers a comfortable medium temperature around 20 °C (range: 18-26°C), but the Active Thermal Control System (ACTS) is critical in keeping the station livable and enabling important scientific equipment to conduct the microgravity research that is the station's primary reason for being [ibid].

Humans living and working in space are monitored directly on the body. Since a space suit is like a mini-spaceship, sensors in the body/suit environment include O_2, CO_2, humidity, respiration, heart rate, and metabolic rates (pH and oxygen levels in the blood). The data is transferred to an onboard integrated network for analysis and feedback if required. Requirements for all space suit sensors are that they must be highly sensitive, minimally invasive, operate in near-real time, and easily repairable or replaceable. The system must also be compact, able to function independent of gravity and temperature fluctuations, low power and require minimal human interaction [49].

Application and Accessibility of climatic information: Spacecraft and spacesuits provide an abundance of system status telemetry. The data is monitored in real time using text or graphical displays that incorporate limit checking and trend analysis. Ground personnel at mission control constantly look for anomalies to detect changes and support decision making. The corresponding data is archived to allow for further analysis [49]. New mission control data visualisation systems, such as Open Mission Control Technologies (Open MCT) are evolving that can '...display streaming and historical data, imagery, timelines, procedures and other data visualizations, all in one place...' with a goal to achieve improved mobile support and better synchronisation of data across platforms [50].

Private or Public Relevance: There are single sensors, multiple sensors (combination of a variety of sensors in one apparatus), and sensors as substantial part of control loop equipment onboard the ISS (e.g. as part of the overall ECLSS) [46] While some sensors are related to crew and station health, others provide specific measurements in research facilities and to dedicated experiments. The general data pathway for extra-terrestrial monitoring and control is between the space-based occupant and mission control, thus privacy is managed via a system that ensures that the environment remains entirely habitable for all occupants.

4. CAPE as a Concept in constructing the CAAS Wardrobe

By evaluating the boundaries between body and the environment, a wardrobe - a personal and portable habitat - can serve as climate indicator. The case studies conveyed that telemetry and spaceship parameters, such as climate monitoring and control, are important factors for crewed habitats. From these terrestrial and extraterrestrial perspectives we propose CAPE as a concept both at the scale of personal and global relevance.

CAPE, as a system concept can curate sensor data on a city or neighbourhood scale bringing in potentially billions of datasets generated by millions of sensor variants. These sensors can be embedded into wearables, automobiles, bicycles, urban furniture, urban lighting fixtures, buildings, etc. The data from these sensors can be collated, cleaned, storied using the IoT devices and can then be analysed using Big Data Analytics. Sensor datasets representing almost any physical-world attributes and readings can be ingested.

CAPE is about wearing information in a way that the passerby senses the exchange and understands what you have seen, where you have been and hence, what they are moving into. Like a delayed mirror, CAPE assists your mind, allowing you to sense where you are going. It is not a case of changing what one wears to move into this new space but instead about having knowledge of what you are moving into. To ascertain a visual understanding of the parameters of CAPE a series of bricolages were stitched together (figure 13).

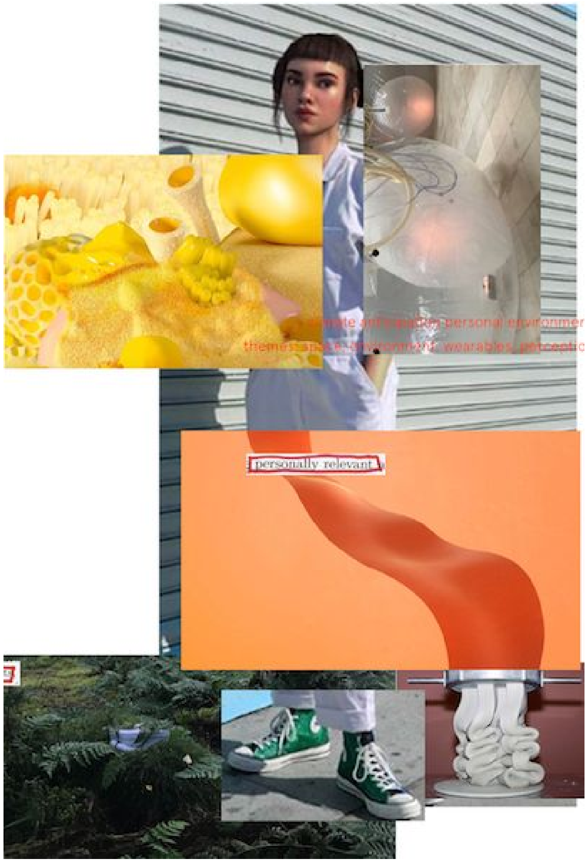

Figure 13. A bricolage of CAPE influences (Credit J. Cunningham)

The concept of anticipation is core to CAPE. When defining anticipation, Anderson [25] draws a distinction between calculating, imagining and performance. We recognise these as interdependent and we propose that anticipation should take into consideration shifting modalities, scales and materials. When these anticipatory practices overlap this gives rise to the fourth dimension - communication (figure 14).

In addition to anticipation, CAPE proposes to shift the dialogue from speculation to care to allow for more localised approaches focussed on the present. Speculation follows Donna Haraway's pairings with fabulation and fiction whilst recognising how CAPE has a grounding in science fact. We consider the relationships surrounding and emerging from anticipation - affect as a subjective state for the individuals in a commons, care as a local way to consider the human, survival as a state of preparation and speculation as a critique of the possible.

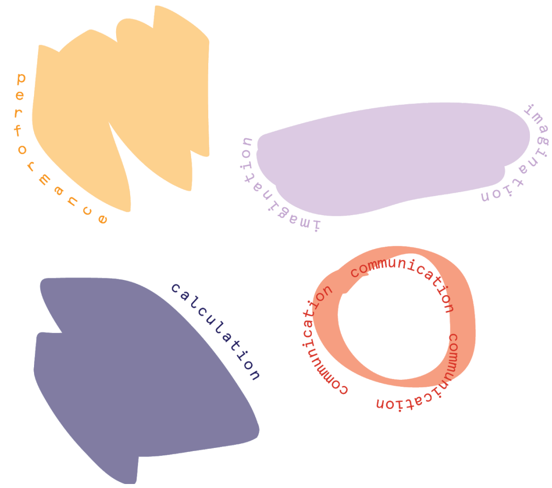

Figure 14. First four gestures of the CAPE alphabet. (Credit J. Cunningham)

The relationships at play in the CAPE framework are visualised in Figure 15 as overlays, confrontations, and questions. **If** speculation is understood as being future focussed, the present-day applications invited by anticipation seem more relevant to be applied to CAPE, a wearable climate indicator. **If** anticipation is an affective state, then it can be understood as a quartet of performance, calculation, imagination and communication, all of which can be applied at various scales of understanding. CAPE gathers and translates both quantitative and qualitative data to establish a space for co-owned narratives. These narratives are not restricted to words. The ground-up and top-down gathering methods have the capacity to be predictive, as apparel that reflects our experience and relationship to the climates we inhabit. The circular visualisations are comprised of separate fragments of big and small data. This modular system is similar to Anouk Beckers' critical dressing development [51] that requires the wearer to piece together separate pieces. The engagement requested by the parts creates both an active wearer and an interchangeable approach to clothe oneself. The individual anticipatory qualities of CAPE - performance, calculation, imagination and communication - are overlaid by the patterned gestures that make up CAAS - cities, technology, environment, and society (as shown earlier in Figure 1). Being worn by a digital avatar whose reality has been

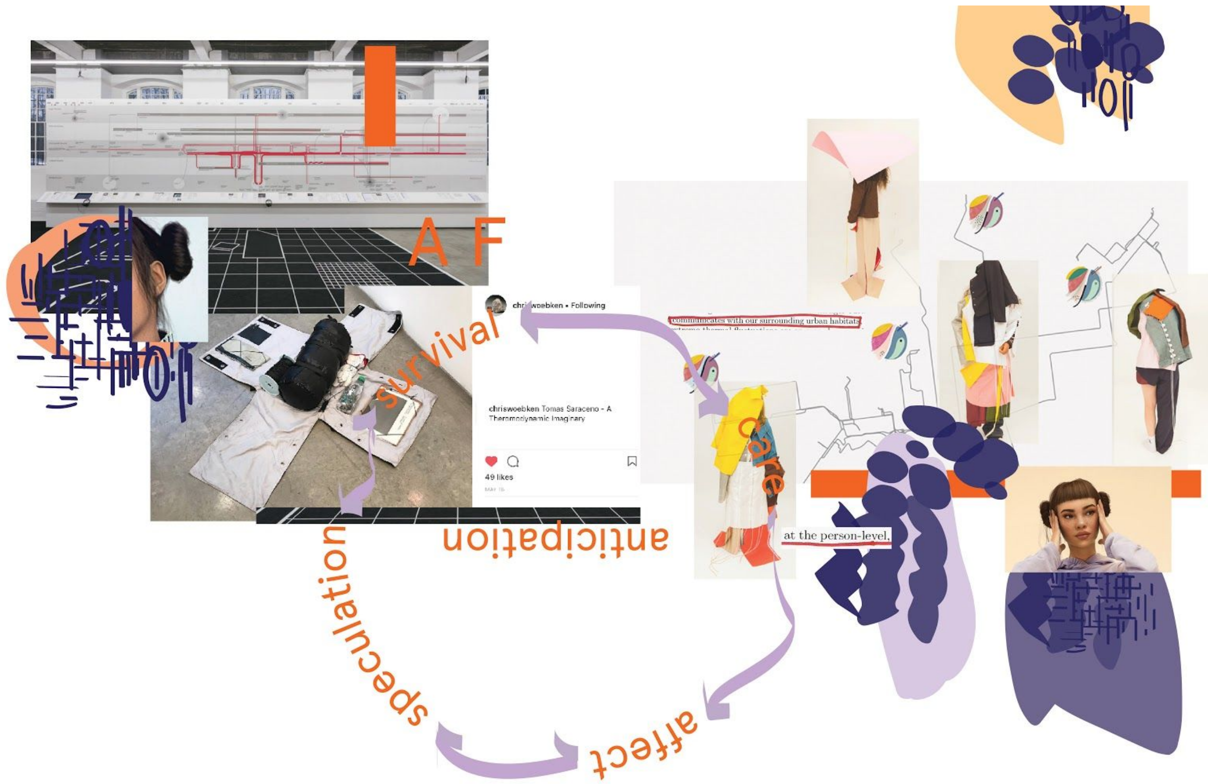

Figure. 15. CAPE Framework (Credit J. Cunningham)

queried, due to her insertion into more-than-human scenarios, provokes an evaluation of the boundaries between the body, surrounding bodies and environment. The backdrops of an uber city and a National Park enable CAPE to be understood in contrasting environments of development and preservation, of the built environment and surrounding ecosystems.

CAPE is interchangeable. The affective wearer is considerate, challenged and navigating an objective critical space during what becomes a routine activity. By overlaying modular wearables over a narrative mapping it is possible to understand the body in relation to these spaces and collected data streams. The data collected and distributed by CAPE is composed of wild facts which have the ability to destabilise narratives. When society co-produces this evidence, CAPE materialises possible and actual ways for humans to attune to climate for public benefit and more sustainable future urbanism. This message corresponds with Tomas Saraceno's "aerocene urbanism" [52] stimulating CAPE towards the capacity of imagination in foresight and the ability to engage global communities locally.

5. Discussion

In recognising our desire to anticipate our environment, to understand climate at a local scale, and the urgency of such information, we acknowledge that the unknown is becoming more complex. Living in space requires the constant monitoring of data, the accumulated confirmation of what is safe and what is not. Having drawn inspiration and evidence from the narrowly defined environment of the ISS, there is appreciation for the complexities of streaming and displaying data, imagery, and the synchronisation across machine platforms. To be alert, to react, to anticipate; these are the critical behaviours that influence the way people use things in terrestrial and extraterrestrial environments.

CAPE is worn – it is wardrobe. Like a coat, like a shirt, like a shoe, like a sensor – it is external to our body. It is wardrobe as sensor, but not for our consumption, but as indicator of our accumulated bubbles for others. The amalgamation of our shifting position through the environment – a sampling of each minute environmental bubble we pass through. CAPE is the real time visualisation of accumulated motion – motion of manus and machine – displayed for the benefit of those we greet, meet and pass by. By viewing the information we wear, wearers can make nuanced changes to their routes, compare the information with past experience, understand what is to come in its immediacy and anticipate what may come after.

While static, we interact with our environment, we affect our surroundings, we create the layer of warm air, we raise the humidity as we emit moisture, heat and off gas. Our wardrobe is an intermediary; it is comfort, it can be part of the bubble and, it can shield the environment. But we are not singular beings, we move in groups, we exchange with others and in doing so we alter our immediate environments in multiples. Anticipatory qualities overlap and develop, patterned gestures exchange with one another.

While in motion, we become part of the environment and it becomes difficult to distinguish our contributions with the contributions of others as our bubbles intermingle, mesh and influence each other. CAPE is about the collective and the individual, aggregated and discrete.

6. Conclusions

This paper was a step into the theory and context of CAPE. The methods and definitions embedded within the work of Forensic Architecture and Donna Haraway allow CAPE as '*material intelligence'* to confirm itself as grounded in an evidence-based approach through science fact, speculative fabulation and societal fictions. Thus, diagnostic and predictive analytics using small data and big data can be applied to humans and human collectives in creative ways to inform them about the parameters of their immediate environment/s and to mitigate harmful climatic conditions.

Speculation is understood as being future focussed, thus the present-day applications invited by anticipation are relevant to CAPE as climate indicator. With anticipation as an affective state, CAPE applies the quartet of performance, calculation, imagination and communication to various scales of understanding. Shifting the dialogue from speculation to care allows for more localised approaches focussed on the present. Since CAPE has a grounding in science fact, it is pertinent that care becomes a local way to consider the human, with survival as a state of preparation.

The next step is to explore the practice of CAPE by generating exercises in remote sensing, monitoring and processing data and exploring visualisations as wearable climate dialogues. We will seek ways to collect, aggregate, integrate, analyse and curate, anonymously enabling us to not only recognise, but to act, react, and 'affect' insights and actionable climate intelligence.

References

[1] M. William, How to Dress in our New World, in: H. Julavits, L. Shapton, S. Heti (Eds.) Women in Clothes, Penguin, UK, 2014, pp. 246-247.

[2] D. Haraway, SF: Science Fiction, Speculative Fabulation, String Figures, So Far, 2013, https://adanewmedia.org/2013/11/issue3-haraway/ (accessed 01.08.18)

[3] L. Johnson, Heat health risk prompts change to Environment Canada warning system, 27 July 2018, https://www.cbc.ca/news/canada/british-columbia/heat-warning-change-environment-canada-1.4762636?cmp=rss, (accessed 01.08.18).

[4] B. Kahn, We just breached the 410 parts per million threshold, 20 April 2017, http://www.climatecentral.org/news/we-just-breached-the-410-parts-per-million-threshold-21372 (accessed 08.08.18).

[5] R.D. Brown, Ameliorating the effects of climate change: Modifying microclimates through design, Landscape and Urban Planning, 100:4 (2011) pp. 372-374.

[6] Vanos, J.K., Warland, J.S., Gillespie, T.J. et al, Thermal comfort modelling of body temperature and psychological variations of a human exercising in an outdoor environment, Int. J. Biometeorol. 56: 21 (2012) pp.21-32.

[7] G. Mills, H. Cleugh, R. Emmanuel et al, Climate Information for Improved Planning and Management of Mega Cities (Needs Perspective), Procedia Environmental Sciences 1 (2010) pp.228–246.

[8] S. Lenzholzer, R.D. Brown, Climate-responsive landscape architecture design education, J. Cleaner Prod. 61 (2013) pp. 89-99. (http://dx.doi.org/10.1016/j.jclepro.2012.12.038)

[9] Mapbox Data Visulisation https://www.mapbox.com/use-cases/data-visualization/ (accessed 08.08/18)

[10] D.E. Holmes, Big Data A Very Short Introduction, Oxford University Press, Oxford, UK, 2017.

[11] D. Laney, 2001 https://blogs.gartner.com/doug-laney/files/2012/01/ad949-3D-Data-Management-Controlling-Data-Volume-Velocity-and-Variety.pdf (accessed 08.02.18)

[12] E.R. Tufte, Envisioning Information, Graphics Press, Cheshire, Connecticut, 1990.

[13] J. Boehnert, Data Visualisation Does Political Things, Design Research Society Conference, Design Research Society: Future-Focused Thinking, Brighton, England, 2016, 27—30 June.

[14] S. Fairburn, S., Mohanty, B. Imhof, City As A Spaceship (CAAS), Paper IAC-14-E4.2.8 presented at the 65th International Astronautical Congress, Toronto, Canada September 2014.

[15] D. Hill, The Street as a Platform, 11 February 2008,http://www.cityofsound.com/blog/2008/02/the-street-as-p.html, (accessed 08.08.2018).

[16] The Senseable City Lab (MIT) http://senseable.mit.edu/ (accessed 08.04.18)

[17] L. R. Messeri, Placing Outer Space: An Earthly Ethnography of Other Worlds, Duke University Press, Durham, NC, 2016

[18] G.E.P. Box, (1979), "Robustness in the strategy of scientific model building", in Launer, R. L.; Wilkinson, G. N., *Robustness in Statistics*, Academic Press, pp. 201–236.

[19] D. Hannah, C. Selin, “Unseasonal Fashion: A Manifesto” in Climate Architectures and the Planetary Imaginary, in: J. Graham (Ed.), Lars Mueller Publishers, Columbia, 2016, pp. 222—231.

[20] S. Mohanty, S. Fairburn, Skins by Design: Humans to Habitats, International Conference On Environmental Systems, Vancouver, Canada, 2003, 7-10 July.

[21] S. Watkins, L. Dunne Functional Clothing Design From Sportswear to Spacesuits, Fairchild Books, 2015.

[22] M. Webb, (1968) Cushicle and Suitaloon: In Archigram 8 (original) reproduced via http://architecturewithoutarchitecture.blogspot.com/p/cushicle-and-suitaloon-were-conceptual.html (accessed 08.07.18)

[23] F. Berardi, Grga Basic, We Can, http://c4sr.columbia.edu/projects/we-can, (accessed 10.09.2018).

[24] Forensic Architecture, “Counter Investigations”: (Exhibition), 7 Mar-18 May 2018. Institute for Contemporary Art, London, UK.

[25] B. Anderson, Preemption, precaution, preparedness: Anticipatory action and future geographies. J. Progress in Human Geographies. 34,6 (2010) 777-798.

[26] V. Adams, M. Murphy, A.E. Clarke, Anticipation: Technoscience, life, affect, temporality. J. Subjectivity. 28 (2009) 246–265.

[27] N. Di Battista, On Imagination, Domus Magazine, 1011 (2017) 14 March.

[28] M. Garces, Honesty with the Real. Journal of Aesthetics and Culture 4, 1 (2012) 1-6.

[29] A. Jain, J. Ardern. Truth is a matter of imagination, Due 78, 20 July 2018, http://due.aaschool.ac.uk/wp-content/uploads/2016/10/180717-DUE78-B5-Jul-03-interact.pdf (accessed 29.08.18).

[30] D. Haraway, Making Oddkin: Story Telling for Earthly Survival, Wilbur L. Cross Medal for Distinguished Alumni Public Lecture, Yale University, 2017, 27 October.

[31] A. Dunne, F. Raby, Speculative Everything: design fiction and social dreaming,MIT Press UK 2013

[32] M. Ward, The Life and Death of Critical and Speculative Design: Post-Truth, Post-Capital and Post-Disciplinarity in Perilous Times, Critical by Design? Potentials and Limitations of Materialized Critique, Academy of Art and Design FHNW, Basel, 2018, 17-18 May.

[33] Bose, M. (2007). The Design Studio, A site for Critical Enquiry in Design Studio Pedagogy: Horizons for the Future, A.M Salama and N. Wilkinson Editors, The Urban International Press, Gateshead, UK.

[34] Centre for Science and Environment, Air Pollution Report card *https://www.cseindia.org/delhi-ncr-air-pollution-reportcard-2017-18-8521* (accessed 09.10.18)

[35] Centre for Science and Environment (CSE) Personal Interview Transcript Feb 2015.

[36] Anumita Roychowdhury, Vivek Chattopadhyaya and Shambhavi Shukla, (2015) REINVENTING AIR QUALITY MONITORING Potential of low cost alternative monitoring methods, Centre for Science and Environment, New Delhi. http://cdn.cseindia.org/attachments/0.85392300_1505190810_reinventing-air-quality-monitoring-potential-of-low-cost-dec27.pdf

[37] Lufdaten Measuring fine dust itself. 2018 https://luftdaten.info/ (accessed 06.22.18)

[38] Weis, M. Particulate matter sensor network, NASA Space Apps Challenge, https://2016.spaceappschallenge.org/challenges/earth/aircheck/projects/particulate-matter-sensor-network (accessed 29.08.18).

[39] London C40 Cities 2018 https://www.c40.org/press_releases/london-bangalore-aq (accessed 28.08.18)

[40]] L. Mittal and G. Fuller (2017) London Air Quality Network Summary Report 2016, https://www.londonair.org.uk/london/reports/2016_LAQN_Summary_Report.pdf (accessed 28.08.18)

[41] NASA Terra Moderate Resolution Imaging Spectroradiometer (MODIS) 2018, https://terra.nasa.gov/about/terra-instruments/modis (accessed 28.08.18)

[42] K.J. Maji, A.K. Dikshit, A. Deshpande and P.C. Speldewinde (2016) Human health risk assessment due to air pollution in 10 urban cities in Maharashtra, India, Cogent Environmental Science, 2:1, DOI: 10.1080/23311843.2016.1193110

[43] B.Bowe, Y.Xie, T. Li, Y. Yan, H. Xian, Z. Al-Aly The 2016 global and national burden of diabetes mellitus attributable to PM2·5 air pollution https://www.thelancet.com/journals/lanpla/article/PIIS2542-5196(18)30140-2/fulltext (accessed 28.08.18)

[44] ERASMUS Centre, Environment Control and life Support System (ECLSS) Factsheet, 2010. http://wsn.spaceflight.esa.int/docs/Factsheets/30%20ECLSS%20LR.pdf (accessed 07.22.18).

[45] NASA 2013 https://www.nasa.gov/content/cooling-system-keeps-space-station-safe-productive

[46] C. Stenzel, Deployment of precise and robust sensors on board ISS—for scientific experiments and for operation of the station, Anal Bioanal Chem (2016) 408: 6517. https://doi.org/10.1007/s00216-016-9789-0

[47] NASA, Environmental Monitoring, 2012 https://www.nasa.gov/mission_pages/station/research/experiments/Environmental_Monitoring.html, (accessed 07.22.18)

[48] E. Sharifahmadian, Y. Choi, L.S. Shahram, New sensors could evaluate astronauts' vital signs in flight, SPIE Newsroom, DOI. 10.1117/2.1201402.005321, http://spie.org/newsroom/5321-new-sensors-could-evaluate-astronauts-vital-signs-in-flight?ArticleID=x106286&SSO=1 (accessed 07.22.18)

[49] D. L. Iverson, (2008) System Health Monitoring for Space Mission Operations, IEEE, https://ti.arc.nasa.gov/m/pub-archive/1389h/1389%20(Iverson).pdf (accessed 09.24.18)

[50] NASA (2018) Open MCT (Mission Control Technologies) https://nasa.github.io/openmct/about-open-mct/ (accessed 09.24.18)

[51] A. Beckers, A Modular System for Garments https://rietveldacademie.nl/en/page/1019708/anouk-beckers (07.22.18)

[52] T. Saraceno Aerocene 2018 http://aerocene.org/ (accessed 09.24.18)