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Understanding Working Scenarios of Urban Air Mobility

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Abstract

Urban Air Mobility (UAM) can provide new air mobility faster and avoid city traffic with the growth of new technologies. But they need to be co-developed with the city infrastructure. Thus, understanding the working scenarios of UAM and how they will interact with the city and the other modes of transport systems is vital. Storyboarding helps policymakers, city planners, designers, and investors better understand the product's contextual interaction over time. This process allows the design team to be implicit or express a design that is easy to understand, reflect upon, or modify.

Keywords: design methods, product design, visualisation, urban air mobility

1. Introduction

India, the seventh-largest nation in terms of size with over 1.38 billion in population, has one of the largest transport sectors in the world. A steady influx of people into the cities combined with a very high growth rate of cities has led to an ever-increasing burden on the existing infrastructure or roadways, leading to a less efficient and congested transportation system. There is an exponential increase in the need for On-Demand-Mobility (ODM) or personalised transportation systems (Sharma et al. 2011; Greenblatt and Shaheen 2015). Urban Air Mobility (UAM) provides an opportunity for cities to take the pressure off the already over-used ground (or even underground) infrastructure (Becker *et al.* 2018; Justin and Mavris 2019; Shihab *et al.* 2019). This technological advancement needs to be co-developed with the city infrastructure so that UAM can mature as a product and service and not just a technocrat innovation (Miaskiewicz and Kozar 2011; Ulrich 2016). This research is a part of doctoral research on the development of UAM in India. The research project's goal was to document and understand users' needs, wants and concerns and explore the form of UAM to satisfy the user. During the research, it was evident that different working scenarios play a vital role in the general use and design of UAM. To comprehend the evolution of UAM in the given context, one has to understand the varied working scenarios of UAM and their interaction with other modes of transport. Thus, a storyboard method was used to understand the working of UAM and how they will interact with the users and other modes of transport systems. This knowledge is vital in developing a holistic new model of intra-city transportation.

UAM - the transition of the city transport system

In the 21st century, cities are central to economic development and cultural growth; by 2050, they will house over 80% of the world's population (Mitra 2006; Alfarsi 2017). A substantial portion of the country's population is in transit at any given time due to various reasons, causing the number of personal vehicles purchased and consequently in use on the roads to increase exponentially (Singh 2006). In this context, the significance of intra-city transportation is paramount.

Flying cars are not new and were imagined decades ago, and they became popular with The Jetsons - a 20th-century television show where they showcased a city made for flying vehicles (Tucker 2008; Nneji *et al.* 2017). The small aircraft and helicopter market currently caters to a limited clientele due to their high infrastructure costs and highly specialised training requirements (pilot training). The development of UAMs, with their Vertical Take-off and Landing (VTOL) capability, has made an essential contribution to realising the aspiration of a flying car (Nneji *et al.* 2017). UAMs can be fully autonomous or human-assisted, as demonstrated by Ehang, SureFly, Bay Zoltan, e-volo. As things move vertically, UAMs can use the space above the ground to work their way from point A to B, avoiding congestion on the road (Antcliff *et al.* 2016). In combination with the freedom of movement, autonomous flight, and technology, the research and development of technology related to UAM have proliferated (Holmes 2016). The growth of smart cities and the benefit of UAMs can create a new typology of city planning. Current researchers are primarily focusing on the policies for UAMs or the economy of the system or demand estimation or use of technology in the UAMs (Balac *et al.* 2019; Fleischer *et al.* 2019; González *et al.* 2019; Perkins 2021). Thus, there is a research gap in users' behaviour, UAM interaction with other modes of transport or city infrastructure, working scenarios, etc. This research paper focuses on understanding the potential integration of UAMs in the cities and how they will interact with the users and might even impact the development of cities themselves.

2. Methodology

Transport design or city planning involves several stakeholders, including the design team, client, future users, and government officials. Ideas and concepts are generated during the design process and need to be conveyed to these people for comments, judgments, or acceptance, depending on the phase. The storyboard serves as a valuable aid to the designer in this endeavour by providing a common visual language that people of different backgrounds can read and understand. A literature review found very few tools to develop various working scenarios for UAMs. Most of the research papers are based on the technology of the UAM or UAMs' feasibility (Johnson *et al.* 2018; Balac *et al.* 2019; Fleischer *et al.* 2019; Bauranov and Rakas 2021). Thus, this research paper will help urban designers, city officials, etc., visualise and decide the future cityscape. Even though storyboarding is an established design research methodology and is well known in the design community, its use in the field of UAM research gives new insights to both design engineers and city planners. Four different working scenarios were created based on the combined knowledge gained from the literature review (Afonso *et al.* 2021; Bauranov and Rakas 2021), user surveys (Rautray *et al.* 2020), and studying white papers (Holden and Goel 2016). The user survey data were analysed by semantic decomposition and transformation followed by semantic mergence and supplement; finally, consistency scrutiny was done to improve the usability of the findings. They provided insights into users' needs, wants, and concerns regarding UAM and generic travel behaviour. The following section provides an overview of the storyboarding process.

2.1. Storyboarding as a method

In the film and advertising industries, storyboards are widely used. The purpose of storyboards is to previsualize an animated or live-action film through images displayed in sequence. It is essentially a large comic of the film or some portion of the film produced in advance to help cinematographers and directors visualise scenes and identify problems before they occur (Van der Lelie 2006). Similarly, in product design, it allows designers to envision the future working scenarios and how the users will interact with the product or how the product will react to the surrounding and vice-a-versa. The importance of storytelling in planning theory has been widely accepted since the 1990s (Söderström *et al.* 2014). Developing any transportation system requires a multi/ interdisciplinary team because it involves city planners, investors, government officials, etc. At the same time, politicians, policymakers, and private players often use stories about the future to make decisions regarding urban planning (Kenter 2020). Storyboards used in product design and those used in a cinema follow the same visual form of sequencing pictures and words, but their aims and messages are different.

Designers have a significant challenge in unlocking the tacit knowledge of how things should be so that these ideas can be shared, discussed, critiqued, and ultimately operationalised. The challenge is particularly acute when designing physical interactions, where critical aspects are often neither

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verbalised nor materialised (Sirkin and Ju 2014). It is often beneficial to explore and understand people, technologies, and their interactions at an early stage of a design-oriented research project by creating or finding scenarios. This method reveals implicit knowledge and understanding that is not explicitly stated. The traditional process begins with the design team gathering around a whiteboard with sticky notes, creating a storyboard, and defining the interactions they would like to investigate (Kenter 2020). Storyboards are often used as guides for enacting scenarios or designing prototypes. As time passes, they become archives of our original thinking as well as indicators of its evolution (Landay and Myers 1996; Van der Lelie 2006). Storyboarding provokes alternatives and challenges conventional theories by creating interactive dialogues and use-case scenarios. This process allows an individual or a team to implicit or express a design that is easy to understand, reflect upon, or modify. By creating storyboards, the team develops a better understanding of the design problem and creates alternative solutions (Wilson 2002; Klemmer *et al.* 2006). There are two significant advantages of storyboarding for designers:

- The designer can empathise with the user or the circumstance, just like they would while reading a (comic) book or watching a movie. This process creates a common basis for the design team, allowing them to communicate and express ideas. It removes ambiguity and specificity related to one unique discipline (Mollá *et al.* 2018).
- By stepping back from their expertise and experience, designers can view the unfolding event from the outside and reflect on it. This objective viewpoint facilitates analysis, identifying specific components of the interaction, and estimating time progression. The storyboard thus visually represents many of the crucial elements of the context, reminds the design team of these aspects, and facilitates discussions (Van der Lelie 2006).

Types of storyboards in different design phases

The product design process is often divided into several distinct phases. The type of storyboard style varies depending on the requirements of the stage, such as to explore, develop, discuss, or present. Thus, it is critical to match the visualisation style to the design phase. Figure 1 highlights that the storyboard for this research paper is used in the analysis phase of the design process. For this process, we need to map out the working scenarios of UAM using a detailed and factual visualisation style.

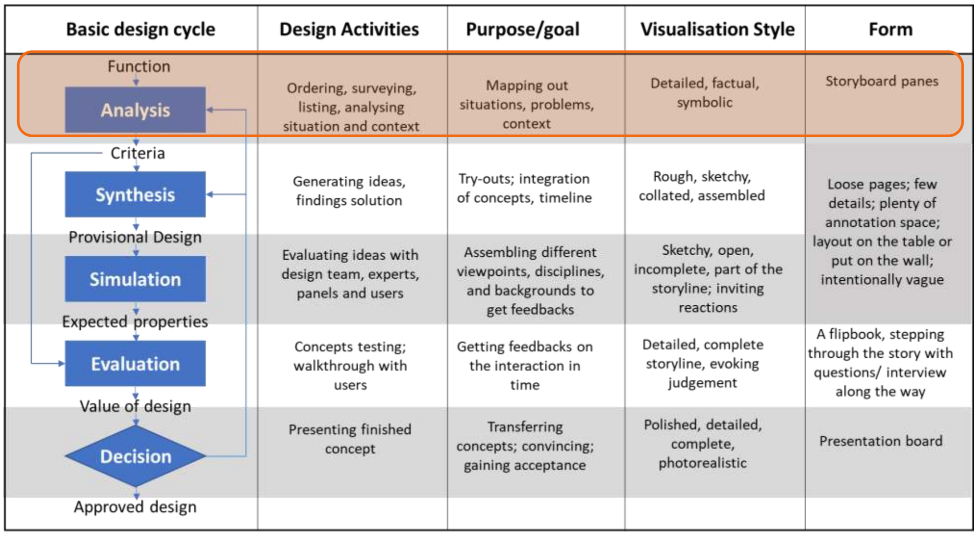

Figure 1. Storyboard in different phases of the design (Roozenburg 1995)

2.2. Types of working scenarios of UAM

Based on the product reviews of existing UAM in markets or at an advanced level of flight testing, the following are the various VTOL technologies: Lift+cruise aircraft (Aurora Flight Science), Compound helicopter (Cater& Mooney), Tilt-rotor aircraft (Joby S2), Tilt-wing aircraft (Airbus Vahana), Multirotor (Ehang 184), Tilt duct (Lilium Jet), Modular system (Airbus Pop-Up), Transformable (Terrafugia), Fluidic thrust augmentation (Jetoptera J-2000) and Cyclocopter (D-Dalus, Russia's

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Redux). Even though there could be more than four working scenarios, as explained below, these are the most probable scenarios based on the maturity of technology, ease of use, and infrastructure required. These VTOL technologies were grouped based on the similarities of working mechanisms and their impact on the vehicles' overall design. A factor or cluster analysis is done to find the relation between the different groups formed, and then the best suitable scenario is selected to represent the group. Depending on the design and working modes, we can divide the working scenarios of UAMs into four distinct modalities at a conceptual level. It helped identify the subtle requirements for implementing UAM, developing required infrastructure, and modification needed for an existing transport system to enable the smooth working of UAM. This research paper also tries to highlight storyboarding as a method that can be used in a technology-driven project like UAM to understand user interaction and product interaction. It emphasises the importance of a user-centre, human-centre approach to successfully incorporate UAM into our cities.

Scenario 1: On-Demand UAMs (fixed propellors)

Most of the current development of UAMs falls into fixed propellers design, which is shown in Figure 2. For example, Multirotor UAM- Ehang 216, Tilt-rotor aircraft - Joby S2, Tilt-wing aircraft – Airbus Vahana, Lift + Cruise aircraft -Aurora Flight Science, Tilt duct – Lilium Jet, Compound helicopter, etc. Even though these UAMs provide a fast urban transportation system, they cannot offer effective last-mile connectivity (unless the users have vertiport). Users either must walk or drive to the nearest vertiport for the service.

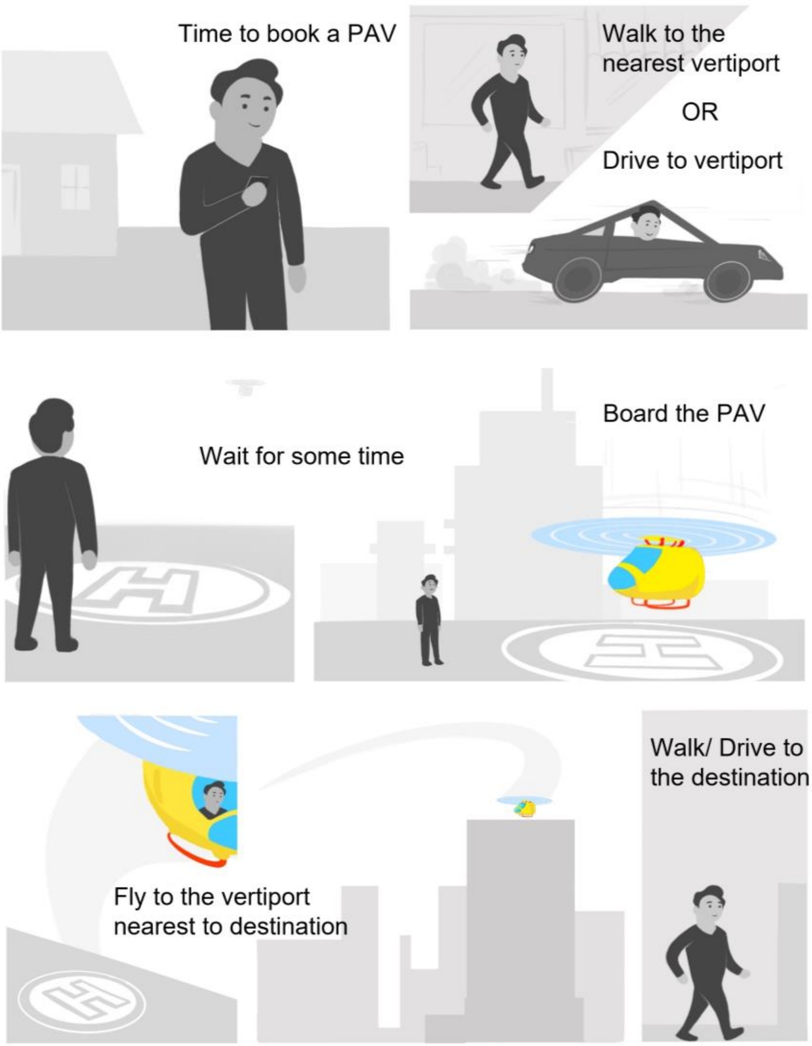

Figure 2. Illustration for fixed propeller UAM

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Volocopter, Lilium Jet and Uber Air are a few companies that have already proposed this mode of working scenario. This scenario will require the construction of vertiports at strategic locations, well connected to other public transport systems, have ample parking space for private vehicles, etc. This scenario fits well with a transport conglomerate or large operators like Uber or OLA and needs significant to moderate infrastructure development throughout the city. They can be planned with other modes of transport systems to provide a seamless and efficient intra-city mobility solution.

Scenario 2: Re-formed UAMs (Option-1)

The second scenario deals with modular propellers design where the rotor housing can be separately booked per the requirement. The land vehicle needs to sync with the rotor module and have a specific attachment mechanism for the flight mode, as shown in Figure 3 (example: UAM being developed at IIT Hyderabad – sixteen multi-rotors UAM). This system creates a modular flying structure that can be attached with specially designed passenger cars or goods carriers depending on the requirements. This scenario reduces the initial cost of infrastructure development as part of it is bore by the customers. It will also improve the last mile connectivity and connect cities with satellite towns.

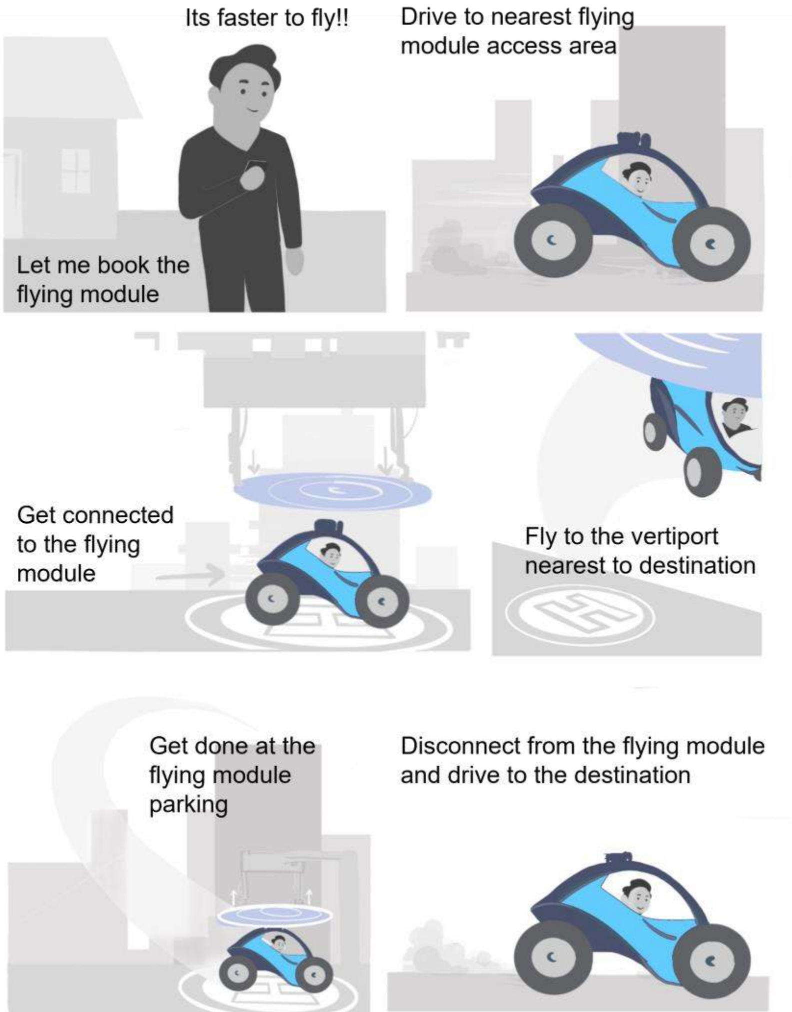

Figure 3. Illustration of a modular system for UAMs (Option-1)

These vehicles will require a universal connector and intelligent materials to reduce the overall weight. Vertiports for Re-formed UAMs will require storage and charging facilities for the modular propeller structures. This system will require the development of flying module storage and charging facilities at various locations. The success of this model also depends on the automobile sector working in tandem with UAM operators to make modifications to automobile design.

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Scenario 3: Re-formed UAMs (Option-2)

Another version of the second scenario, as highlighted in Figure 4, is that there could be a modular flying propeller structure that can be ordered and easily attached to the user's road vehicle and fly to the destination (example: Airbus Pop-Up multi-rotors). In this scenario, the user does not require driving to the modular flying structure, but they can order them to a location of their choice. This system requires more advanced technologies and coordination between the road vehicle and the flying structure. Like the previous scenario, the infrastructure cost is divided between the user and the service providers.

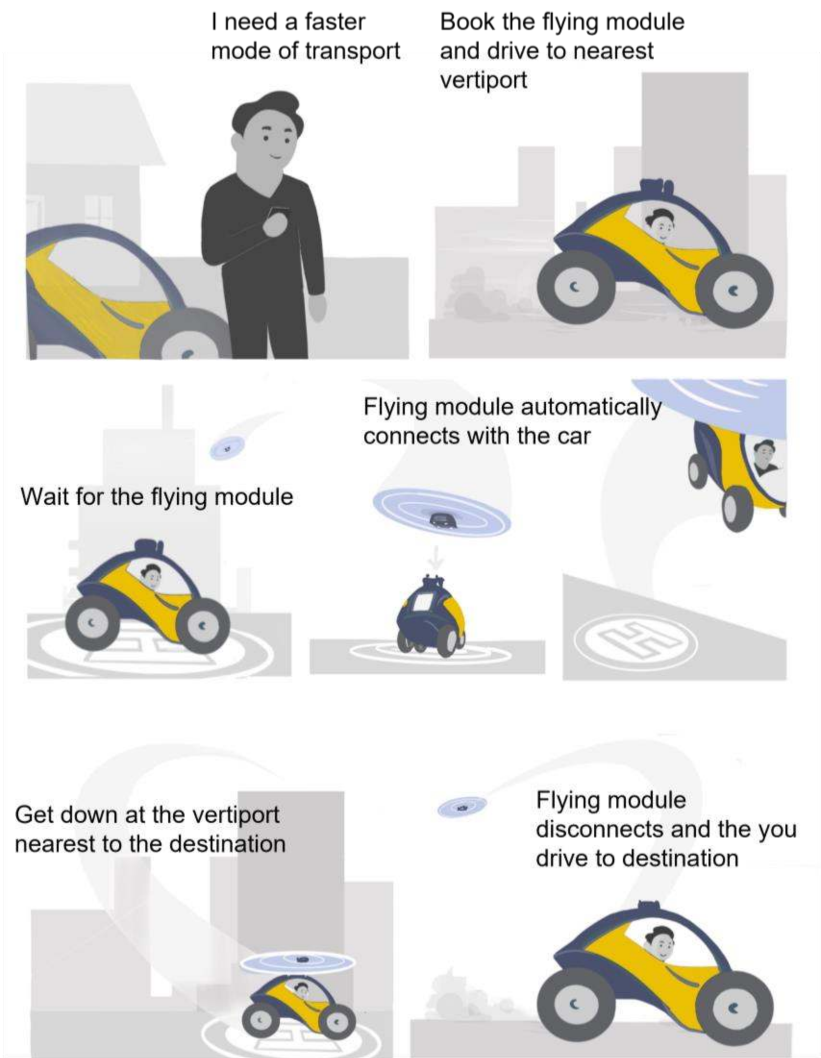

Figure 4. Illustration of a modular system for UAMs (Option-2)

Even though this working scenario gives more freedom to the users, it will require more advanced air traffic controllers, better connecting mechanisms, better battery management systems, etc. This scenario requires fewer flying module depots than the previous one, as the flying module can come to specific users. Airbus Pop-Up has already demonstrated the concept vehicle based on the scenario.

Scenario 4: Transformable UAMs or Flying cars

The fourth scenario is based on a transformable vehicle system that is roadworthy, for example, Terrafugia, PAL-V. The user can ride to a vertiport/ open parking space to transfer into an air vehicle, fly to a vertiport/ open parking space nearest to the destination, and transform back into a road vehicle. This seamless transition requires no external support system other than designated open space to transform. These vehicles may require a short runway or have VTOL capabilities, as shown in Figure 5.

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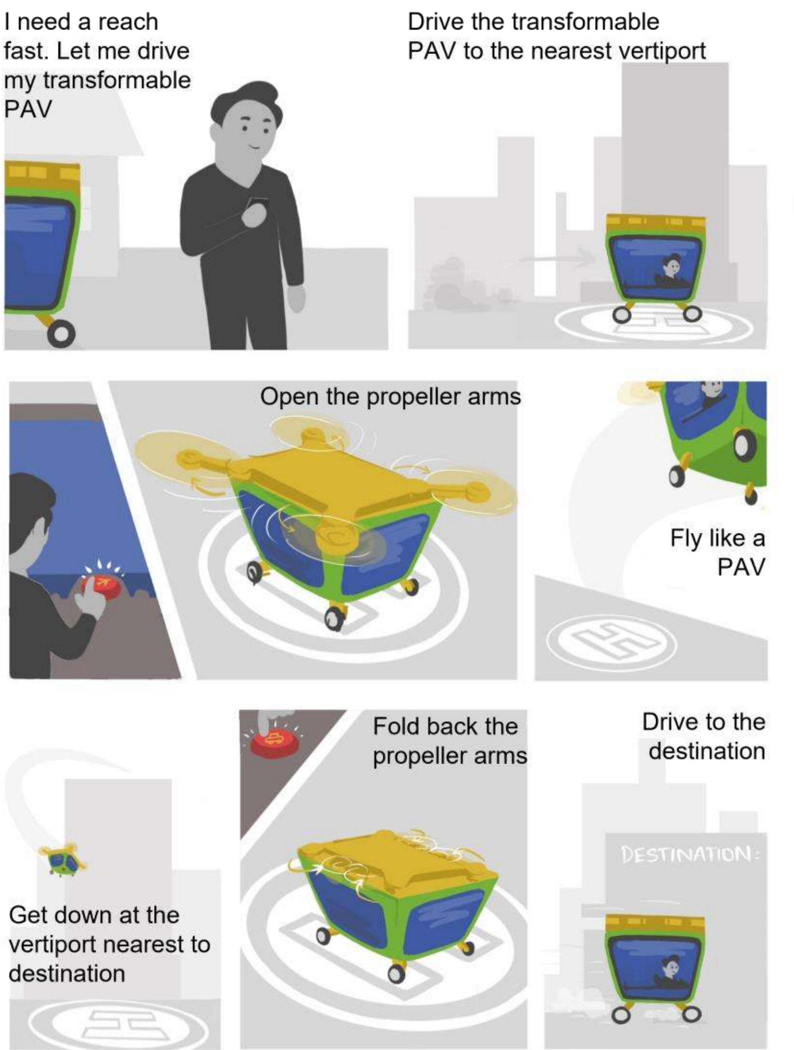

Figure 5. Illustration of transformable UAMs or flying cars

These UAMs can be fully autonomous, where the Artificial Intelligence decides the optimal route, the destination, and the land vehicle's transition to flight mode. On the other hand, it can be semi-autonomous. The user can drive the vehicle on the road and decide when to transform it into a flying car (this scenario may require the user to have both valid driving and pilot licences). This scenario required a designated open space or vertiport and air traffic control system on a city planning level. The user bears the cost of the vehicle, thus reducing the cost of infrastructure development.

3. Discussion and limitations

The above storyboarding illustrates the difference in the working scenarios of UAMs and how the user will interact with the new mode of transportation. These are part of the doctoral research activities done by the researcher to gain insights into the working of the UAMs. The overall working of the UAMs also depends on the VTOL technology and the system design (operation). VTOL plays an essential role in defining the working of the UAM; technologies such as Multirotor, Tilt-rotor aircraft, Tilt-wing aircraft, Lift + cruise, Tilt duct, Compound helicopter are more suited to working Scenario 1 and can have both pilot and autonomous capabilities. Modular systems based on multi-rotor, fluidic thrust augmentation, or ducted rotors can be used for Scenario 2 and 3. Transformable technologies such as folding wings with push propellors or foldable multi-rotors are best suited for Scenario 4. Based on the working scenarios, we foresee having three fundamental UAM systems in practice: Conventional UAM (require trained pilot), Evolutionary UAM (semi-autonomous) and Revolutionary UAM (fully autonomous).

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Limitation

These four working scenarios showcase the most prominent archetypical UAMs for public transport in general, and there could be a few more working scenarios not included in this research. For time consideration, alternative combinations and mergers between the modes were not included in the research activity. There are a few other examples of Personal Aerial Vehicles (PAV) such as jet-packs, flying hoverboards, flying bikes, etc. Even though these PAVs offer great excitement, they were not selected to develop the storyboards due to the safety considerations, particular skill set required to operate such vehicles and are inappropriate for public transport. Another criterion for choosing these four working scenarios was that these scenarios should work well in existing Indian cities and future smart cities. These four storyboards were based on the current technologies that have demonstrated the working prototypes. Many new technologies may evolve in the future, and we may need to create new storyboards to understand the working scenarios of those new UAMs and the infrastructure requirements.

Insights for city infrastructure requirements for UAM

Companies worldwide are racing to build UAMs and certify them for commercial use. This drive puts pressure on cities and government agencies to develop laws for utilising urban airspace, which is difficult given the wide range of designs and sizes, agility, speed, take-off processes, automation, etc. Based on the storyboarding of the working scenarios, the following infrastructure (system) need to be developed in the future at the city level to support these UAM working scenarios:

- Irrespective of piloted or autonomous UAMs, the city needs to develop a robust air traffic control and management system to monitor and control intra-city air travel.
- For scenarios one and two, the city needs to develop vertiports connected to other modes of transportation for ease of operation. These can be operated by large conglomerates or by government agencies.
- For scenarios three and four, the city needs to build designated parking spaces for UAM operation. Roads and other means of transportation should be well connected to these parking spaces.
- The vertiports designed for On-Demand UAMs should have enough parking space for private vehicles. Scenario one requires centralised ownership with proper storage and charging facilities.
- Geo-fencing and tagging of UAMs are necessary to improve safety and efficiency.
- Classification of urban air space will improve the density of UAM operations.
- Urban design needs to evolve to cater to the needs of UAM operations, such as multi-level parking, building design, avoiding overhead electric cables, multi-modal transit hubs, etc.
- Cities may have to develop a new database management centre to handle the registration and record of UAMs.
- A robust security system is required to ward off hacking and terrorist attacks.
- Determining the no-fly zone to improve privacy, reduce noise level and avoid collisions can go a long way in enhancing the working of UAM in close to residential or institutional areas (Bauranov and Rakas 2021).

4. Conclusion

This paper demonstrates how storyboarding was used in the design process that provoked alternatives and challenged conventional theories by creating interactive dialogues and use-case scenarios. Using storyboarding, we illustrate the difference in working scenarios of UAM and how the user will interact with this new mode of transportation. Storyboarding helps product users better understand the product's contextual interaction over time. This process allowed the design team to be implicit or express a design that is easy to understand, reflect upon, or modify. The storyboarding shown within this paper facilitated analysis, identified specific components of the interaction, and enabled estimating time progression. The field of research UAM is relatively new compared to other modes of transport like buses, railways or

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airlines. Most of the research on UAM is either on technology or the policies or economic feasibility of this new transportation medium. This research paper tries to address this research gap by using storyboards as a visual medium to represent crucial elements of UAM working within various city contexts. It also showcases the novel use of a storyboard as a design thinking and discussion tool in the technology-driven field of UAM. This process is an essential activity as it facilitates discussions and helps remind the design team of critical aspects of the project. The parameters of infrastructure required for a successful UAM implementation were explored and documented by this method. The research finding will help city planners and other officials gauge the amount of work needed to realise this new transportation medium. From a generic point of view, this research illustrates how creating a storyboard at the initial stage of the design process for any technology-driven project will help find subtle nuance about the product or its interaction with the users or other products. The findings from such research will lead to improvements or modifications that will support the product's success.

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