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Building resilient and user-centred rail carriage designs for the future: A literature review

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Abstract

This paper will review the literature surrounding resilience theory and how its application to the design of future rail carriage interiors can make for a more resilient and user-centred experience. This review will use the Melbourne rail transit experience in Australia as a reference for exploring the application of resilience theory towards rail rolling stock interior design, with a particular focus on the operational design life of the vehicle. Currently, ideas of resilience are being applied to urban cities and infrastructure by urban planners and engineers. However, this has lead to a focus on becoming resilient towards sudden, major disruptors such as natural disasters, or a focus on building robust infrastructure based on material durability. This review does not lie with the aforementioned issues, but rather uses an industrial design perspective to explore how specific public transport assets, such as rail rolling stock, are affected by the emerging focus on resilience theory within various fields of study, forming the contribution of this paper. Key findings show there needs to be a better understanding of how a resilient rail carriage interior design can support a more user-centred travel experience. The user-centred perspective of resilience explored in this paper serve to complement efforts in transport planning and user-centred engagements by operators.

1. Introduction

Public transport provides efficient mobility for cities and has a key role in achieving inclusivity by meeting the needs of anyone wanting access to what mobility can afford, such as jobs, education, healthcare and access to the community (Governments, 2011, Tovey et al., 2016, Burdett, 2011). The continued development of rail and the commuting experience through the design of rolling stock, can increase passenger satisfaction, further retain public transport users, increase competitive advantage for operators, as well as improve quality of life. Rail has a strong determining influence on the future characteristics, identity, and built environment of its city (Ren and Yeo, 2006, Votolato, 2007, Vuchic, 2007, Tovey et al., 2016, Tovey, 2016). There are a number of changes afoot in urban cities such as Melbourne— increasing urban populations, growing urban sprawl as well as demographic changes such as an ageing society and changing millennial travel behaviors (Delbosc and Nakanishi, 2017, Heilig, 2012, Currie and Delbosc, 2010). New travel demands are emerging such as an increase in part-time workers compared to full-time workers, suggesting a heavy need for travel flexibility. Flexible trips are often multimodal, and will rely on a heavy rail backbone (Schmitt, 2015, Mees and Groenhart, 2014, Melbourne, 2015). Melbourne's public transport industry is also now moving towards 24-hour services, allowing for more time coverage, while also building out the rail network in order to reach the expanding urban sprawl (PTV, 2012). As designers and planners begin to consider the future travel experience, they do so in an emerging landscape of informed and selective contemporary customers, expecting customized and innovative product experiences within the emerging experience and service economy (Lorentzen, 2009). These future contexts provide challenges for the sustainability of travel experience amongst users. Increasingly, authorities are looking to reframe the approach towards urban cities and public transport assets through the concept of resilience.

Within transport literature and practice, ideas of resilient thinking are beginning to emerge, although, mainly addressed through transport/urban planning and engineering fields. Typically, the definitions of resilience within these fields primarily address durability of materials, such as in engineering literature, or disaster management, such as in planning literature. Resilience theory, therefore, represents a departure from typical sustainability aims and thinking, which is referred to as being a utopian goal of a steady state. Resilience, on the other hand represents opportunity for growth, improvement and embracing of change (Davoudi et al., 2012, Vale, 2014, Martin and Sunley, 2015, ABC, 2018, Fleming, 2016). Melbourne's rail infrastructure continues to expand due to travel demand on the public transport network, however, there is little literature addressing how the design of transport assets might become resilient to possible futures that are rapidly changing in a techno-economic paradigm (Beecroft, 2016, Lorentzen, 2009). This paper explores how a user-centered approach towards designing rail rolling stock can contribute to a more resilient in-vehicle journey experience and public transport service.

Resilience is explored through an examination of industrial design, architecture and the application of the core concept of resilience to the design of rolling stock. The application of resilience theory allows the opportunity of a more user-centric system to be explored for the operating design life of rolling stock. One that serves to complement the current engineering dominated forms of practice. This review will use an exploratory style to help understand the topics mentioned thus far more broadly and will seek to address the application of resilience theory towards transport assets as a gap in the literature; disciplinary differences in the application of resilience theory; as well as elements from the design domain that contribute to the understanding of resilience theory in the literature gap. This paper does not claim to provide a final definition or framework for the application of resilience towards the design of public transport assets such as rail rolling stock, but seeks to introduce the concept in application to the design of rolling stock, as well as add to discourse between public transport and resilience theory.

2. Resilience theory literature review

There is currently a paradigm shift in how researchers and planners view the world, as well as how public transport authorities, academics and professionals are increasingly choosing to frame urban cities and their public transport experiences. Resilience is an increasingly used term in both academic and government publications. This represents a shift from seeing phenomena as reasonably predictable, to the acknowledgement of the complexity, uncertainty and unpredictability of change. (Davoudi et al., 2012, Fleming, 2016). The use of resilience within public government planning reports is described as an 'umbrella', 'buzzword' or catch-all term that is often poorly defined (Lu and Stead, 2013, Martin and Sunley, 2015). In order to better understand the concept of resilience, its current use within Australian transport and planning publications is highlighted, as well as its differing use amongst different fields of study.

2.1. Resilience within Australian transport and planning publications

Resilience is increasingly used in many government and professional publications within Australia regarding transport, infrastructure and city planning. Resilience within urban planning is superseding the paradigm of sustainable development and is seen as a new perspective on community development and socioecological responses to rapid and unpredictable changes (Lew, 2014, Fleming, 2016). Sustainability is concerned with mitigating or preventing changes in order to maintain a normative state, whereas resilience is concerned with adapting to anticipated and unanticipated disruptions (Lew, 2014). A simple definition of resilience refers to the "ability for a city to absorb disturbance while maintaining its functions and structures" (White, cited in Lu and Stead, 2013). While the definition of resilience is often not clearly defined in these reports, the subject matter consistently refers to the resilience of structures and functions, as well as climate change, environmental threats and disaster management (Lu and Stead, 2013). Examples include focusing on the ability for public transport infrastructure to withstand changing climates (Public Transport Victoria, 2015-2016, Infrastructure Victoria, 2016), as well as creating insurance plans for at risk communities in the face of unexpected events (Resilient Melbourne, 2016-2017). When planning for a resilient city, Ahern (2011) asserts that the new paradigm within the urban world appears to be a more holistic outlook which considers not only physical, environmental and disaster management, but also social factors such as equity and human experience. This major shift in thinking about resilience is represented in a global project by the Rockefeller Foundation called '100 Resilient Cities'. Where 100 city strategies, including Melbourne, Australia, are being developed to give decision makers a roadmap to meet the urban resilience needs of the modern city. These urban resilience projects have chosen a more holistic approach which also choose to address aspects of human experience, such as through the focus on health and wellbeing, community and society, in addition to the traditional infrastructure and environmental focus within urban planning.

Resilience is a term that is still being developed in the public transport space and has yet to determine a meaning in reference to the design of public transport assets. Barring the use cases found within Resilient Melbourne (2016), resilience within Australian planning and transport literature has referred to resilience when addressing natural disasters or the resilience of people within urban cities. While more transport orientated reports such as PTV (2012) addresses specific assets such as rail, they tend to refer to the ability of the asset or infrastructure to withstand climate change or natural disaster pressures. This highlights a gap in the literature of how rail rolling stock is not currently being considered to be resilient in its design when referring to experience of the service for people. A more resilient design that is future-focused can potentially improve customer and asset interfacing, as well as service experience, operation and competitiveness for operators.

As the theory of resilience enters many academic fields of study, there is also criticism from some authors regarding discipline specific concepts and theories that already address some of the attributes that resilience is representing. Within economics literature Martin and Sunley (2015) posit parallels between the idea of 'bouncing back' originally suggested in ecology literature by (Holling, 1973) and the concept of 'self-restoring equilibrium dynamics' in economics literature. Whether this detracts from the contribution of applying the theory of resilience to a discipline is not an area that is being addressed in this paper. However, resilience in its simplest sense can be used as a transdisciplinary cornerstone for exploring reactions to future uncertainty and change. In addition, it serves as a way to bridge changing attitudes towards how to approach dealing with a rapidly changing future.

2.2. Resilience disciplinary differences

Early disciplinary contributors to the theory of resilience used different parameters for considering the failures and successes of resilience, as well as what is considered a disturbance, shock or impact. However, the core concept of resilience remains similar across all these fields, which is the capability to recover and return to a steady state after a disruption (Bhamra et al., 2011). There are opposing and varying thoughts towards whether a disturbance must be considered a large shock, or whether more minor shocks or 'slow burn' scenarios are also included. The theory of resilience has a strong grounding in ecology literature, referring to as the "magnitude of disturbance that can be absorbed before a system changes its structure" with a focus on the ability to adapt to an alternative equilibrium state or states (Holling, 1973, Fleming, 2016, Davoudi et al., 2012, Holling, 1996). The concept of resilience grew to develop a strong basis within psychology and sociology

(Richardson, 2002, Greene et al., 2004, Keck and Sakdapolrak, 2013, Hosseini et al., 2016) when referring to individual coping capacity and post-disaster societal recovery; and engineering (Bhamra et al., 2011, Holling, 1996) when referring to the physical properties of materials or the ability for a system to "bounce back" or return to a "pre-disturbance state" when disturbed.

From these early contributors emerged three sets of abstract thoughts and definitions on what constitutes resilience. These abstract definitions of resilience have been incorporated and paralleled in emerging relative definitions of resilience in fields of study that are beginning to incorporate the theory. More recent contributors to the discussion of resilience have further built upon originating definitions as well. Such as within planning when referring to urban planning and landscape architecture (Lew, 2014, Lu and Stead, 2013); economics (Martin and Sunley, 2015); business and organisational management (Carlson et al., 2012, Hosseini et al., 2016, Bhamra et al., 2011); as well as design, when referring to disciplines such as Industrial design and specifically referring to the design of consumer products (Haug, 2018).

Many recent adopters to resilience theory derive their definitions from a combination of existing conceptual frameworks of resilience developed within ecology, psychology and engineering, as well as existing theories within the respective discipline (Davoudi et al., 2012, Martin and Sunley, 2015). For example, Martin & Sunley (2015) draw parallels between concepts in economics as well as the theory of engineering resilience, comparing the idea of being able to 'bounce back' in resilience to 'self-restoring equilibrium dynamics' in mainstream economics. In the design sphere, the combination of existing disciplinary theories and resilience theory can also be seen to combine with the Design for Sustainability (DfS) field within design (Ceschin and Gaziulusoy, 2016, Haug, 2018) as well as notions of product obsolescence (Cooper, 2016, Walker, 2012). Discussed here will be definitions within engineering, ecology and psychology, as well as more recent definition developments in resilience theory, of evolutionary resilience, which explores the ability for a system to not only adapt, but also to be able to evolve and improve.

2.2.1. Engineering

The engineering domain, which typically addresses technical systems such as electric power networks or the material durability of infrastructure, refers to the ability for a state to return to its original intention. This is often referred to as a 'pre-disturbance state' (Holling, 1996) or as being able to 'bounce back' to an 'equilibrium state' (Davoudi et al., 2012). The emphasis that differentiates the engineering definition is that the state is returned to what it originally was, with the original state being one that is steady and at equilibrium. A shock or impact is considered to be anything that disturbs this steady equilibrium state. In addition, engineering resilience is acknowledged as being more focused on mitigating disturbances, such as through risk management, rather than adapting as a result of a disturbance (Fleming, 2016). The notion of engineering resilience is commonly implied within government and professional publications concerning public transport infrastructure and networks and how they might cope with material wear, as well as the impending impacts of climate change (Deloitte, 2017, Infrastructure Victoria, 2016, Public Transport Victoria, 2015-2016, Resilient Melbourne, 2016-2017, UITP (International Association of Public Transport), 2017).

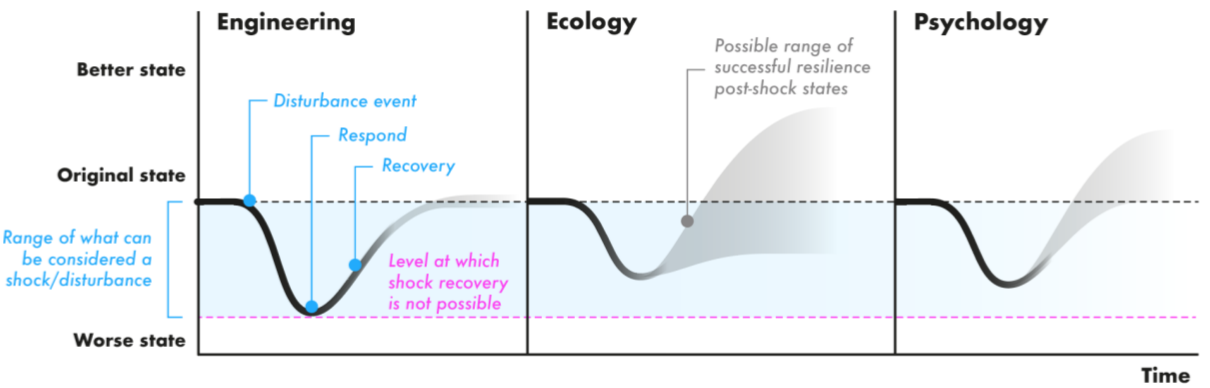
2.2.2. Ecology

The ecology domain addresses the resilience of a system as the ability for a state to adapt itself to a different equilibrium. The definition here, consists of multiple equilibria states, where when a disturbance occurs, there is a 'flip' into an alternative possible equilibrium state (Holling, 1996, Davoudi et al., 2012). This alternative equilibrium could be new, but is not necessarily better or worse, just different (Lew, 2014, Davidson, 2010). Within ecology there is also a differentiation between resilience and sustainability, where sustainability is referred to as being a steady state. Sustainability also bears similarity to the engineering definition of resilience where a system might be in 'equilibrium'. Fleming (2016) also adds that sustainability is operated as a form of utopianism, where systems are clearly mapped out in order to have a balance of stocks and flows, as well as being based on the idea of a stable state view of the world. Resilience can be seen as a more pragmatic approach, with dynamic equilibrium states, compared to sustainability, and seems to be the replacement term, or 'buzzword' within everyday discourses (Davoudi et al., 2012, Vale, 2014, Martin and Sunley, 2015).

2.2.3. Psychology

Sociological or psychological resilience concerns the coping capacity of people (Fleming, 2016). This form of resilience applies anywhere from individuals to groups of people at many scales, such as couples, schools, and even on the larger scale of communities, e.g. in the City of Melbourne in Australia (Resilient Melbourne, 2016). Interdependence of issues within psychology can become as complex as the reader cares to make (Richardson, 2002), the same can be said for the application of resilience amongst other domains and disciplines. Richardson (2002) notes that disruptions can be minor or on the level of traumatic, with either level of disruption giving potential for growth. Within professional and government documents however, a shock or impact is generally heavily implied as being extreme, such as traumatic events, or on the level of natural disasters (City of Melbourne, 2015, Resilient Melbourne, 2016). Compared to ecological resilience, psychological resilience is considered unsuccessful if the shock or impact leaves a person in a worse state compared to the original state.

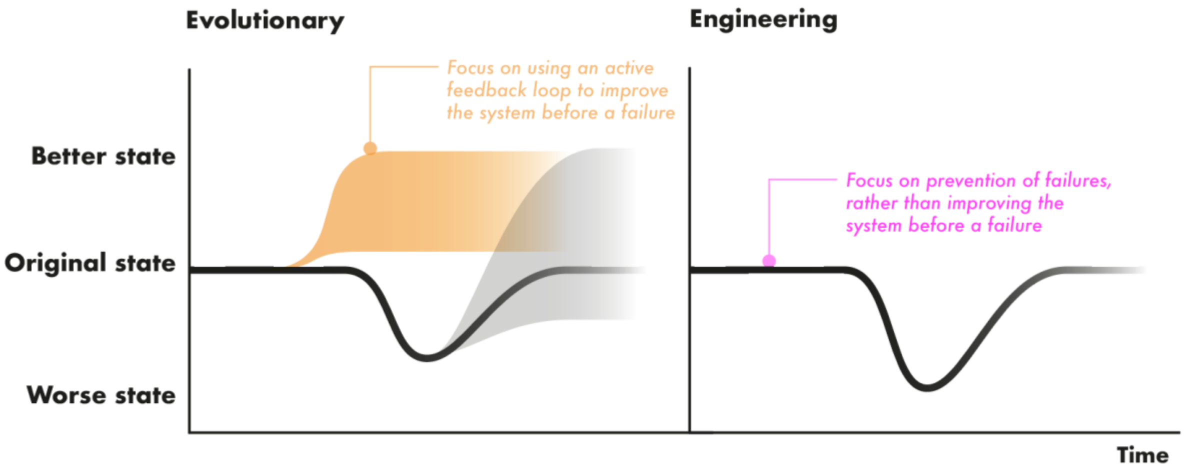
Figure 1 Conceptual comparison of Engineering, Ecology and Psychological resilience



2.2.4. Evolutionary resilience, adaptability and developments in resilience theory

Evolutionary resilience places an emphasis on improvement, of 'bouncing forward' in a transformative or progressive manner. This is in contrast to the traditional term of 'bouncing back', which may be can also be associated with moving back towards a regressive state. As returning to a pre-disturbance state implies that no improvement has been made (Shaw, 2012, Vale, 2014). Change is considered constant, which can be on the scale of slow and fast change, immediate or future time scales, as well as on small or large magnitudes (Davidson, 2010). The notable difference compared to previous definitions of resilience is challenging the idea of equilibrium or the steady state being the end state, traditionally presented in ecology (Martin and Sunley, 2015, Davoudi et al., 2012). In addition, improvement of the object of analysis does not necessarily need to be due to the occurrence of change (Davoudi et al., 2012). Evolutionary resilience can be seen as a more active approach in response to change compared to previous definitions. Adaption, modularity and an active feedback loop are also essential components of evolutionary resilience, which further its more active approach (Davoudi et al., 2012). The more active approach contrasts with how previous definitions from engineering, ecology and psychology choose to tackle pre-disturbance and pre-shock states, which is through robustness, preparedness and mitigation measures (Carlson et al., 2012, Hosseini et al., 2016).

Figure 2 Comparison of Evolutionary and Engineering resilience



2.3. The application of resilience theory

Within academic literature amongst many disciplines, resilience can differ in definition and is often relatively defined in relation to the discipline it is being used within, such as ecology, psychology, planning, economics or engineering (Holling, 1973, Holling, 1996, Lu and Stead, 2013, Richardson, 2002, Martin and Sunley, 2015). Within any discipline or field of application, providing meaningful references can qualify and ground definitions (Martin and Sunley, 2015, Carpenter et al., 2001, Vale, 2014). Thus, this paper will address four fundamental aspects of references for resilience found in the literature. It is these fundamental questions that the exploration of the application of resilience theory to the design life of rail rolling stock in Melbourne will draw its basis from:

1. The resilience of what characteristic?
2. To what kind of shock or impact?
3. By what means and processes?
4. What does the outcome of the recovery from shock look like?

3. Resilience applied to the design life of rail rolling stock

Trains are considered to be Complex Product Systems (CoPS), as they are business to business capital goods that form the backbone of modern society (Ren and Yeo, 2006, Vuchic, 2007). CoPS further differentiate themselves from consumer goods as they often require multiple specialist teams for successful product development and are typically produced in small batches (Hobday, 1998). Public transport assets, with government and regulator involvement, such as trains are understudied within CoPS literature. Instead, mass-produced CoPS goods such as mobile phones, or batch manufactured goods such as airplanes tend to be more available and discussed within the literature. Furthermore, the integration of the design process within the product development and product lifespan operation phases for CoPS is understudied, which tends to focus heavily on engineering approaches (Wang and Suo, 2017, Prencipe, 1998, Tahera et al., 2012). For example, iterative processes within industrial and product design development serve their purpose by moulding the user experience, whereas iterative processes discussed within CoPS literature tend to focus on heavily engineered components, such as turbine engines and less so on customer facing components (Tahera et al., 2012, Buchenau and Suri, 2000). The aforementioned process comparison leads to addressing the first reference question when exploring the application of resilience from section 2.3., which asks, the resilience of what characteristic?

Drawing on the developments in resilience theory and using an evolutionary resilience basis, the characteristic in focus is the user experience of passengers interfacing within the rail carriage interior environment. User-centred design is becoming more of a focus within transport industries who are looking to understand and better address user needs, leading to higher levels of profit, customer retainment, user activity and competitiveness (Camacho et al., 2016). This can also be seen in the increased level of user and stakeholder consultation in the development of new train fleets, when compared to previous train fleets, such as in the consultation of Melbourne’s High Capacity Metro Trains (HCMT) (State of Victoria, 2018). The traditional approach to designing rail carriage interiors produces a one-size-fits-all design that is optimised towards peak hour periods (Vuchic, 2007). This static design approach is understandable, as public transport users have diverse abilities, requirements and needs associated with their travel experience, as well as the cost and practicality of a homogenous fleet. Compromises are often appropriate in trying to fulfil these needs and expectations in a way that does not compromise the majority (Stickdorn et al., 2011, Tovey, 2016). A resulting reliable and safe service is the foundation for any acceptable travel journey, however it is not necessarily one that represents a good travel experience (See Figure 3). A good travel experience is fulfilled when the foundations of safety and reliability, ease and comfort are met, with the expectations and wants of users representing points of improvement, or even customer delight, rather than a benchmark (van Hagen and Bron, 2014, Beirão and Cabral, 2007).

Figure 3 Pyramid of customer needs, adapted from van Hagen and Bron (2014)

Needs and requirements from users can change based on context, forming the additional basis that user experience changes based on the needs of the moment, otherwise known as being ‘fit for purpose’ (Schmidt III and Austin, 2016). Resilience can be achieved on one time scale, while failing in another time scale, with period of time chosen leading to different parameters for defining success when discussing being fit for purpose and resilience (Carlson et al., 2012, Fox, 2016, Brand, 1995). Something can be resilient on one time scale, and fail in another. Placing an emphasis on time, means that an object is no longer static in space, but rather, dynamically interacting with context, resulting in changes in shape and form as a result of changing forces (Schmidt III and Austin, 2016, Kronenburg and Klassen, 2006). Applied to the design of rail rolling stock, context is defined in terms of time, space, use, performance and location, whilst also addressing external macro level political, economic, social technological and environmental demands (Schmidt III and Austin, 2016, Thompson et al., 2011). The evolving context of a space means that place, people and purpose must fit together in order to drive performance and experience (Schmidt III and Austin, 2016). Staying ‘fit for purpose’ emphasises the human-object relationship and manages performance slippages between appropriateness of the object and demand for use by people. It has also begun to be redefined by some manufacturers as a “living space in motion” (Grey, 2018). Acknowledging the changing contexts in which the rail carriage must operate within, questions the performance slippage between a peak hour designed rail interior and an off-peak demand for use, such as within a 24-hour public transport service that Melbourne aims for (PTV, 2012). This idea of performance slippage can be taken further when discussing other variants of context throughout time, such as warm and cold weather changes, where bicycle racks on trains in Europe are diminished in the winter and fully installed in the summer (Cerny and Daggers, 2016).

3.1. Challenges for design

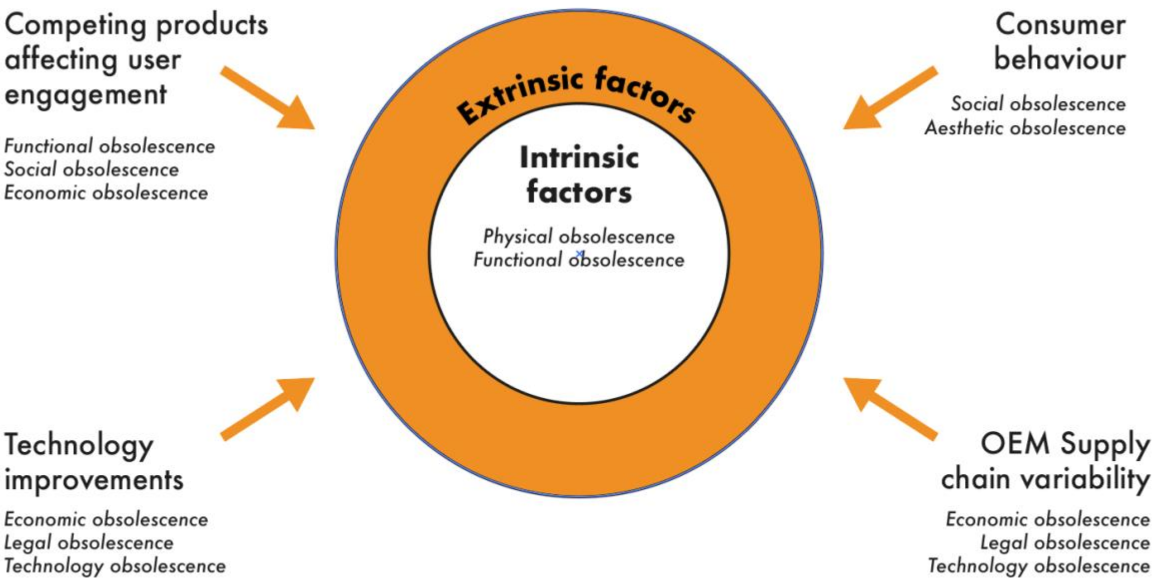
Managing fitness for purpose requires an understanding of the challenges, shocks or impacts that might affect the resilience of a design. This leads to answering the second question, resilience to what kind of shock or impact? Within product design, there are many different ways of measuring disturbances, shocks and impacts. These are commonly termed as obsolescence in the design domain. Obsolescence is defined by Langston et al. (2008) as the inability to accommodate change, resulting in a mismatch between user needs (demand) and product capabilities (supply). There are many facets of obsolescence described within product design literature, these highlight the interdisciplinary nature of design, but also serve as a foundation for framing resilience (See Table 1).

Table 1 Types of obsolescence (Cooper, 2016, Walker, 2012, Schmidt III and Austin, 2016, Vuchic, 2017, Langston et al., 2008, Haug, 2018)

Physical	When natural decay over time or accelerated deterioration from internal and external factors leads to reduced physical performance. This can be due to factors such as weathering, wear and tear through age and vandalism.
Functional	When user needs and objectives change from the intended original function. This can be due to a change in context of use.
Social	When cultural or social responses change, perhaps due to a period of pressure for change related to health or environmental awareness, influencing people’s behaviours. Other influencing factors include demographics, lifestyle, social agendas, urbanisation, or a change in skills such as becoming more technology savvy.
Economic	When repair, maintenance, reuse or upgrade is too costly to be justified by the operator, manufacturer or consumer.
Aesthetic	When a state of newness has worn off, as well as relating to fashion and style, where annual, seasonal or social changes may carry significance.
Legal	When regulations and standards are updated and revised, or changes to government grant incentives.
Technological	When older technologies are superseded, allowing for lighter, handier construction techniques, as well as new functions and better performance.

The design of rolling stock is often heavily focused on quantifiable aspects, as these often have clear and binary definitions of failure. For this reason, physical, economic and legal obsolescence have a heavy focus in the design and engineering processes of rolling stock. The design and engineering processes for developing rolling stock tend to refer to the engineering definition of resilience, which focuses on prevention, mitigation and material durability. Aesthetic, functional and social factors, such as fashion trends and changes in user needs, can be more subjective as they often occur on the individual level where people have their own behaviours and attitudes. What constitutes a successful user experience can be objectively quantitatively measured, however it also contains many subjective and qualitative aspects that cannot be measured. The same can be said for what constitutes an unsuccessful experience. The types of failure listed in Table 1 point to specifics, however it is often a combination of these factors lead to can lead to a lack of resilience. Haug (2018) categorises these as extrinsic forces and intrinsic forces, whereby extrinsic forces are those that act upon the product, while intrinsic forces are characteristics relating to the product itself. Figure 4 represents a modified version of Haug's (2018) 'Causes for Product Replacement' diagram, which has been adapted to better reflect the forces affecting CoPS, rather than consumer products. A more contextual view allows a dynamic equilibrium of multiple states to be experienced, which is fit for purpose to user needs. This contrasts with traditional engineering approaches of the design of rolling stock interiors, where a mid-life refit may give only two designed states over a lifetime. The variable nature of user needs and desires requires the development of dynamic products (Cooper, 2016). Rather than predetermined predictions, the relationships between users and space should be able to grow over time, through the use of modular and re-configurable space, which allows users to become co-authors in their experience (Fox, 2016, Dunne, 2008).

Figure 4 Extrinsic and Intrinsic factors affecting product resilience, adapted from Haug (2018)



3.2. Individual processes for maintaining resilience

A one size fits all mentality means that a product, space or environment is in a constant static state. Rather than being a one-time, permanent, ergonomic solution for all tasks, a successful space needs to be adaptable and able to be negotiated by users dynamically through time (Fox, 2016, Vischer, 2009, Brand, 1995, Orpilla and McKee, 2017, Alexander, 1979). Schmidt III and Austin (2016) define adaptability as "the capacity of a [structure] to accommodate effectively the evolving demands of its context, thus maximising its value through life." Being able to adapt to change means avoiding the types of obsolescence outlined in Table 1 which result in the inability to accommodate change. Changes, such as social shifts (causes), can require a physical reaction (effect), such as a change in layout or function within a space or environment. However, not all changes are necessarily manifested physically, some can also be accommodated organisationally through the operator, as well as through the structure's latent capacity and the individual interacting with the environment themselves (Schmidt III and Austin, 2016, Fernandez, 2003, Kohlert and

Cooper, 2017). Rail travellers can interact with their environment individually by modifying flip seats, perch seats or bench backs that swing back and forth to face the direction of travel (Coxon, 2015, pg 119, Symes, 2013). Even without these inherent structural changes, travellers will ultimately try to adapt the environment to best suit their needs, using the structure's latent capacity, such as finding a suitable place to work on-board, or finding a quiet area on-board as a reaction to crowding conditions (Axtell et al., 2008, Hirsch and Thompson, 2011, Thomas, 2009). These examples mentioned are some of the means and processes by which a resilient user experience may be realised. An interior environment that programs multiple scenario buffers allows for designed responses that are adaptable, rather than relying on mitigation measures, which can be seen in traditional engineering views of resilience (Fleming, 2016). However, major changes will require more involved processes that are organised on the operator level.

3.3. Operator processes for maintaining resilience

Typically, the resilience of a rail carriage interior is ensured through a vehicle service maintenance procedure, based on a set time or distance travelled (Vuchic, 2017). A combination of predictive, preventative and reactive maintenance is typically used, involving light maintenance, such as cleaning, to heavier strategies such as vehicle overhaul, dismantling, rebuilding and even refurbishment. These maintenance service procedures tend to be graded alphabetically, such as A, B, C, and onwards, increasing in the intensity of maintenance. For example, an 'A' service will generally include cleaning and light maintenance every 7 days or every 12,5000km. Whereas 'B' services can include general overhaul, after 4 'A' services have happened. 'C' or 'D' services can include more major maintenances, such as major cleans or a mid-life refurbishment and design update. It should be noted that mid-life refurbishments tend to happen every decade or so, as service lifespans of rolling stock tend to typically range between 35 to 45 years (Vuchic, 2007). A typical vehicle service maintenance procedure aligns with an engineering resilience approach, where the focus is returning all components to a pre-disturbance state through means and processes such as cleaning and replacement of damaged components. However, more proactive approaches towards vehicle service maintenance are also emerging within the rail industry, such as condition-based maintenance, where the use of sensors monitor the vehicle/asset during normal operating conditions, as well as modular maintenance techniques, which involves replacing components during light maintenance (i.e. an 'A' service) in order to reduce the need and resources involved for maintaining the whole vehicle at once (i.e. a 'C' service, which may run less often) (Roland Berger, 2017, Roland Berger, 2016). These emerging maintenance techniques not only help streamline the maintenance process, but also provide the potential adaptability to release design updates that may be seasonal. Such as cold and warm weather altercations, or trials of components on certain train lines for user specific feedback contextual to geography. Moving into an evolutionary resilience paradigm within transport planning and design, will allow for better adaptability and fit for purpose-ness of rail in-journey experiences. Achieving this increased level of adaptability will also require increased levels of customer and user feedback (Fleming, 2016, Smith, 2007).

Examples within industry of adaptable and fit for purpose design responses can be seen from rolling stock OEM's, such as Alstom, as well as concept designs from companies such as Airbus and Deutsche Bahn. Growing demand for future rail public transit and designing for a future of increasing and uncertain change has led to adaptability measures from manufacturers such as Alstom, who have developed modular assets across their heavy and light rail products, in order to better meet the requirements of different urban cities (Góngora et al., 2015). Other examples include the European Union financed MODTRAIN project which looks to standardize parts to decrease maintenance and manufacturing costs (Zschiedrich, 2008), as well as the mass customisation of parts within bus design (Napper, 2010). Examples of primarily customer-facing interpretations of adaptability include Airbus's

Transpose modular plane project, which reimagines static aircraft interiors to be multi-purpose and context specific (Fly Transpose, 2018). Similarly, Deutsche Bahn's 'Idea Train' also moves way from a single state interior design and looks at how multiple states could be incorporated into the journey experience for regional rail through different cabin modules (Spannuth, 2017).

3.4. Adaption and feedback processes by operators for individuals

A more involved feedback loop process between the users and operators could mean the incorporation of user testing scenarios where trials of designs are more frequent and users are engaged with much more often. A more active feedback loop will allow for better responses to potential changes and future challenges faced by rail and public transport. Creating an adaptable fit for purpose space enables a more resilient user-centred experience and allows rail operators to continue to stay competitive in their service offerings. A more involved feedback loop process can also be complemented by emerging technologies such as additive manufacturing. The ability for additive manufacturing to reduce supply chain demands by being de-globalised enables parts to be produced on-demand and even on-site by the operator themselves (Kietzmann et al., 2015). The efficiency in customisation by additive manufacturing could allow the implementation of more agile design updates within the operator's capabilities. Which will require further embracing human-centred design principles and techniques throughout the operator's organisation, in order to properly engage users, extract meaningful data, and design adaptable fit for purpose design responses accordingly.

4. Discussion and Summary

Resilience theory is concerned with how to successfully respond to the unpredictability and uncertainty of change, rather than striving for a sustainability paradigm, which is commonly seen as the aim of a utopian steady state with less consideration towards pragmatic responses to disruptions. When referring to the resilience of public transport assets such as rail rolling stock, there is a literature gap to be filled in addressing the resilience of service experience for people. Within urban planning and public transport literature, human-centred experiences such as these are rarely addressed. Instead there is more of a focus on the urban infrastructure durability and functions, as well as susceptibility to climate change and disaster management. Rail is the backbone of many urban cities and it can be more competitively positioned to future challenges and uncertainties by becoming more resilient and user-centred. Applying resilience theory to the design of rail carriage interiors will involve rethinking aspects of the operating life of how the environment and design of carriage interiors interface with users. The operational life of rail carriage interiors has the potential to move towards a much more dynamic design and less of a static configuration. Both in its designed configuration, as well as in how the operators and manufacturers roll out design improvements across the rail carriage fleet. User testing for the purposes of implementing design updates could become more involved with the public as technologies such as Additive Manufacturing (AM) enable operators the opportunity to trial design updates in-situ and in real time. User testing at this level will involve the development of methods that will enable improved feedback loops for performance between users and the operator, such as co-design and design ethnography techniques (Smith, 2007, Sanders and Stappers, 2012, Dunne, 2008).

The notion of a more dynamic rail carriage interior has a particular alignment with Melbourne's emerging urban landscape of a polycentric and expanding city (State of Victoria, 2014). The interfacing of a polycentric and expanding urban form, with the rail carriage, could also point to future rail carriage interior designs that are contextual and geographically aware. Generating a closer connection between the people within these urban forms and the transport infrastructure surrounding them. The Network Development

Plan by PTV (2012) and existing data from (Vicsig, 2018) plan and point towards dedicated rail carriage sets running on train lines. This presents a possible focus for future rail interiors within the Melbourne context to become customized to their dedicated lines and be designed according the specific geographical contexts and needs of the travelers along the line. In summation, the application of resilience theory towards the design of rail carriage interiors for Melbourne affects many areas of the rail carriage operating design life. This represents a response to question 4 of section 2.3, what does the outcome of the recovery from shock look like? Evolutionary resilience has been used as a basis for defining resilient user-centred design for CoPS such as rail rolling stock. Feedback loops are used as an adaptable preventative measure against change and obsolescence, which include design methods and methodologies such as iterative design, co-design and design ethnography. Reactions to unexpected changes and events are characterised as both slow burn and sudden, which can be responded to through the design of the carriage interior environment's latent abilities, as well as through potential operator design and maintenance processes for reconfiguring and updating designs.

Activities that are emerging from a more human-centred design focus, such as the HCMT user testing design engagement (State of Victoria, 2018), can be added to and further developed. In order for this to happen, requirements for human-centred design and user-testing should be implemented into the tendering, contract and Product Design Specifications (PDS) processes of obtaining rolling stock. Within these documents is also the potential for user testing and design updates to be incorporated into the maintenance service life procedures of the vehicle. A more human-centred design process will enable the uncovering of in-depth insights that can contribute to the outcome of a dynamic and contextualised rail carriage interior environment. One that can continually strive to reflect the needs of the people within the city it is serving.

5. Conclusion

The journey experience within train interiors can enhance the competitiveness of travel offerings for public transport in a future where user experience is increasingly being used as a differentiator between transport modes. This review has highlighted some unconventional opportunities for improving said experience, by reframing resilience around the design of rail carriage interiors, as well as providing approaches for engaging in a more user-centric design life and operation of the rail asset. By reviewing resilience theory, its application to rail carriage interior design and operation, as well as literature on obsolescence and fit-for-purpose principles within design literature, it is apparent that there could be a more suitably designed rail carriage interior, as well as specifications for the operational design life of rail rolling stock. Currently, little research has been conducted on the application of resilience theory towards specific infrastructure assets through a design perspective. While resilience theory has been explored within the design domain in terms of consumer products (Haug, 2018), this paper explores the application of resilience theory within the design domain in relation to capital good such as CoPS. Future and further research into resilient design can contribute to creating a more relevant, effective and dynamic train design and operation. Future research should, therefore, further explore the application of emerging technologies such as additive manufacturing, as well as focus on design research methodologies and techniques and how these could be better incorporated within the operational processes of rail rolling stock.

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