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ORIGINAL RESEARCH

# Developing Flexible Risk Management Systems for Resilience in a Post-pandemic World: Can Lessons from a Makerspace Case Study Support Pacific Island Communities?

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***Abstract*** *Pacific Island communities are facing disruptions to supply chains from natural disasters and a changing global environment, which have become more acute following the COVID-19 pandemic. Further, it has been demonstrated how flexible systems can enhance resilience in low-resource environments, such as adapting to changing consumer needs and minimizing supply chain disruptions. This paper considers how the development of a flexible system for conducting a risk assessment on a product that was developed and manufactured in a Makerspace environment would have application in Pacific Island communities to improve resilience. Using a participative action research (PAR) approach, a traditional product risk assessment is refined through iterative PAR cycles to reconceptualize it into a structured simplified risk process. The resulting product development risk assessment process (PDRAP) demonstrates that it is possible to adapt a detailed systematic risk assessment process, such as hazard and operability analysis (HAZOP), to be more suitable and effective for low-resource situations requiring flexible solutions. The improved process provides greater system flexibility to empower people to develop products which may improve their resilience in an ever changing and complex world. The PDRAP process can improve product design and adaptability which assists safeguarding supply chains from system wide disruptions. With the emergence of Makerspaces in developing countries for supply chain recovery from natural disasters and a changing national strategy, the PDRAP provides communities with a low-resource approach for risk assessment to ensure the safe use of products fabricated using emerging low-volume, rapid prototyping, and manufacturing technology.*

**Keywords** Flexible systems · Makerspace · Resilience · Risk assessment · Pacific Islands · Participative action research

## Introduction

The COVID-19 pandemic has highlighted the need for flexible systems that can adapt quickly to changing circumstances (Ishak et al., 2023; Mokline & ben Abdallah, 2022; Zaoui et al., 2023). This need continues in a post-pandemic world where the contextual environment is changing such as the move from global to regional supply chains (Durugbo et al., 2021). Differing contextual environments have varying implications on many business factors (Elias, 2021) including those that affect flexible systems and resilience. Understanding the impact of these aspects is crucial to ensure business continuity and enable responses to future crises.

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The Pacific Islands is a diverse and geographically dispersed region encompassing islands across the Pacific Ocean, with each island possessing its own distinct geographical, cultural, linguistic, and societal characteristics (World Bank, 2022). Pacific Island nations are exposed to external challenges and natural disasters with major consequences (World Bank, 2017). Quick recovery from disasters and external challenges requires systems that are flexible and can adapt to changing circumstances brought about by shocks and disruptions (de Bruijn et al., 2017). Such systems also require adaptability within the changing and heterogeneous contexts of the Pacific Islands.

Flexibility is a critical component of resilience. As the global environment continues to evolve, flexible systems will be necessary to respond to changing market conditions, consumer needs, regionalization, and supply chain disruptions (De la Gala-Velásquez et al., 2023; Settembre-Blundo et al., 2021). Particularly, in regions such as the Pacific, where opportunities for traditional low-cost mass production facilities are limited and natural causes of disruptions are prevalent, organizations and communities that can adjust quickly to changing circumstances will be better equipped to undertake activity to withstand future shocks. The contribution of digital manufacturing technologies which require lower levels of capital, are flexible, and can produce materials on demand is becoming more significant (Wohlers Associates, 2022; Zhang et al., 2023). The theory and strategy behind the increased utilization of these technologies are gaining traction with experimentation (Mourtzis, 2020) and educational opportunities and challenges (Tihinen et al., 2021) provided in research and community environments such as Makerspaces (Hennelly et al., 2019). Makerspaces are collaborative environments that introduce individuals to new ways to make things broadly described under the umbrella term 'digital fabrication' (Gershenfeld, 2012). Therefore, using the theory and knowledge gained to improve flexible systems and build resilience for people living in resource-deficient and marginalized communities (Corsini et al., 2022) who are subject to natural disasters and climate change, such as Pacific nations (Gounder & Xayavong, 2002), is becoming increasingly important (Corsini & Moultrie, 2020).

The emergence of Makerspaces that encourage people to use these technologies is also providing an environment where norms can be challenged, and ideas transformed into products. These Makerspace environments support experimentation, risk-taking, and continuous learning which are synonymous with a culture of adaptability and are also important for effective flexible systems (Friessnig, 2021; Friessnig & Ramsauer, 2021). Within industry-contexts such as humanitarian aid, there are examples of people exploring the benefits and working towards using digital technology and Makerspaces in developing nations. Examples include the use of Makerspaces to assist in reconstructing housing following natural disasters (Barrete, 2023; Communitere, 2022; Magee, 2019), and the development of technology to monitor marine health (Frohock, 2021). Despite the tangible benefits of Makerspaces and their utility in the development of flexible systems, there is currently little literature considering the development of flexible systems in the context of Makerspaces to support resilience-building in the Pacific Island region.

Equally important is rigorous risk management—a critical part of quality manufacturing. However, traditional risk assessments can be seen as inflexible and rigid, with their strict protocols and rules for application. For small developers, this could translate as restrictive, time-consuming, irrelevant, and limiting their innovation and creativity. Indeed, traditional risk assessments might be beyond the small developer's reach. The challenge in the application of rigour and systematic consideration of risk management is to also include elements of flexibility such as described by Sushil (1997) in his description of the connotations of flexibility which include aspects such as localness, variability, compromise, non-rigidity, adjustment, adaptiveness, responsiveness, freedom, agility, and resilience. Improvements in system flexibility can be achieved with an improved approach. The application of risk management processes which is applied to supply chain management, product development, information technology, and marketing areas can also be applied to the development of products in a Makerspace, with its emphasis on iterative and incremental development, collaboration, and continuous improvement. Both groups require a flexible approach to respond quickly to changing circumstances, experiment with new methodologies, and continuously improve their processes.

With this understanding, we therefore propose that the development of flexible systems, such as the reconceptualization of a structured and simplified product development risk assessment process (PDRAP) in product manufacturing within Makerspaces, has an important part to play in the building of resilience for the Pacific Island people. Therefore, with a view to build resilience and meet the needs of the Pacific Islands, the question this research seeks to address is: How can the risk assessment process be refined to enhance the flexibility of product manufacture in a Makerspace environment?

To respond to the research question, this study is informed by a case study focusing on the adaptation of a prototyping, and hazard and operability (HAZOP) risk management process in a Makerspace. This case study and participative action research methodology enabled the researchers to explore the application of the flexible system, the product development risk assessment process (PDRAP), in a Makerspace environment with similar characteristics to the Pacific Island context of enabling resilience-building.

## Literature Review

### Pacific Islands Context and Challenges

The Pacific Island region is characterized by people who have a reverent focus on family (Corbett, 2015; Paterson et al., 2008), a strong desire to overcome the local issues experienced when living in these locations (McNamara et al., 2022) and an emphasis on indigenous knowledge that supports and underpins resilience within local communities (McMillen et al., 2014). Recent challenges experienced by Pacific people include the impacts of climate change (Barnett, 2001) and subsequent threats to food security (McNamara et al., 2022), natural disasters such as tsunami (Lauer et al., 2013), negative economic growth arguably exacerbated by globalization (Gounder & Xayavong, 2002), the management of finite resources (e.g. see Johannes, 2002), and limited access to education, particularly for an increasing young demographic (United Nations, 2020). When challenges like these occur, the Pacific Island people are left to choose how to survive, recover, and put in place strategies to limit or eliminate the impact of future events.

### Building Resilience Through Flexible Systems

Flexible systems refer to systems that are adaptable to changes, be it environmental or social, and respond effectively to these changes (Shukla et al., 2019). In the Pacific nations, flexible systems are necessary, given the region's vulnerability to environmental hazards such as climate change, natural disasters, and sea-level rise (Pacific Community et al., 2016). These systems are needed to build upon existing knowledge and systems (McMillen et al., 2014) to ensure that the Pacific nations can adapt to these changes and develop resilience to overcome the impact on communities.

Flexible systems are designed to be adaptable to changes in the environment (Shukla & Sushil, 2020; Singh et al., 2021). This adaptability is essential in industries such as manufacturing and agriculture, where there is exposure to constant changes in demand and weather patterns. By creating systems that can change quickly to meet new demands, Pacific nations can avoid downtime and maintain continuity in operational activity. In addition, flexible systems play a role in the development of new products and services (e.g. Haleem et al., 2018). By creating systems that can adapt to changes in design or materials, Pacific nations can experiment with new ideas, limiting the need for the expensive reconfiguration of assets.

The resilience literature is amalgamated around the broad concept and disaggregates into many streams which cover both organizational and personal characteristics (Linnenluecke, 2017). In this study, we focus on the stream of literature that informs us about supply chain systems' ability to recover quickly from shocks and disruptions (Christopher & Peck, 2004; Craighead et al., 2007; Ponomarov & Holcomb, 2009). Risk and knowledge management play a pivotal role for improving supply chain resilience to disruptive events by decreasing vulnerability with enhanced flexibility, visibility, and velocity (Jüttner & Maklan, 2011). It is within this context that we seek to understand factors that may have a positive impact on resilience in Pacific Island communities as they are considered some of the most vulnerable due to their exposure to climate change and natural disasters (Kiddle et al., 2017). An attempt to address the concerns faced by these communities led to the establishment of the framework for resilient development in the Pacific (FRDP) which provides guidance towards beneficial activity (Pacific Community et al., 2016). Following guidance in this framework has led to some progress towards improved resilience for climate action and disaster recovery in countries like Vanuatu (Hallwright & Handmer, 2021). By creating resilient community-based systems, Pacific Island nations can recover faster from disruptions and continue to provide for their citizens.

Flexible systems assist organizations and communities to respond quickly to changing needs (Christopher & Peck, 2004; Shukla & Sushil, 2020) and to build resilience to unexpected challenges and disruptions (Carvalho et al., 2012; Khorasani, 2018). Risk management is an approach that allows for resilience to be built on reducing the impact of future disruptions by ensuring they are appropriately managed (Holbeche, 2019).

### Role and Impact of Digital Manufacturing and Makerspaces

Through easy-access computer-aided design coupled with user-friendly manufacturing like 3D printing and laser cutting, almost anybody can be making high-quality and complex products that were once the domain of heavily resourced manufacturing businesses or highly skilled craftspeople (van Holm, 2017). As such, the maker movement represents a kind of democratization of manufacturing (Halverson & Sheridan, 2014). By fostering a collaborative environment, Makerspaces also encourage individuals to share ideas and knowledge, leading to the creation of innovative solutions to various problems (Giannakos et al., 2017). By collaborating with others, individuals can gain new perspectives and insights that they may not have considered on their own (Mersand, 2021; Sharma, 2021).

The role of Makerspaces in building flexible systems and resilience in Pacific nations is becoming increasingly important (Australian Government, 2020). Makerspaces provide individuals with access to advanced tools and technologies that allow them to experiment with new ideas without the need for expensive equipment (Friessnig, 2021; Friessnig & Ramsauer, 2021). By providing individuals with access to these tools, Makerspaces promote the development of new products and ideas, which is essential for building flexible systems. Makerspaces often encourage the free sharing of knowledge fostering a collaborative approach to problem solving (van Holm, 2017; Yang et al., 2022). Makerspaces utilized for product design enable marginalized communities to address issues important to their community (Corsini et al., 2022). The role of Makerspaces in economic development is still uncertain, but there is some evidence that they can play a role in creating cultural changes in communities to encourage entrepreneurship (van Holm, 2017). In Pacific nations, this includes contributing to flexible systems to respond to the disruptions caused by natural disasters and climate change (Australian Government, 2020). The introduction of flexible systems, complimenting risk management to build resilience through the deployment of controls that reduce the likelihood and occurrence of realized risks. These risks arising from disruptions to normal activities due to operational issues or from natural disasters (Kleindorfer & Saad, 2005).

## Risk Identification and Management

Risk identification and risk management is an essential part of product development. The development process involves multiple stages, from ideation to prototyping, to testing, and each stage presents its unique set of risks. Reducing risk during product development is necessary to ensure that the product meets customer requirements, is delivered on time, and is financially viable and safe for people to use. By using risk management processes, product developers can create products that are more likely to meet the needs of the user without expensive and time-consuming redesign processes (Browning et al., 2023).

Risk management processes in product development also help organizations to create products that are better suited to their intended markets. By using prototyping to test and evaluate the product, companies can identify potential issues and make necessary modifications before mass production. By creating products that are better suited to their intended markets, companies can increase their chances of success and improve their ability to adapt to changing market conditions. Some of the best practices for managing risk in product development include the use of failure mode and effects analysis (FMEA), design for manufacturing and assembly (DFMA), prototyping, and hazard and operability (HAZOP) studies (Chauhan et al., 2018; Muda et al., 2022).

By identifying and addressing potential risks early in the development process, companies can minimize the impact of those risks on the final product. For example, FMEA is a proactive approach to identifying potential failures and their effects on the product. FMEA involves creating a list of possible failure modes for each component and subsystem of the product (Haimes, 2016). By using FMEA to identify potential failure modes and their effects, companies can prioritize their risk reduction efforts and minimize the chances of those failures occurring. These processes can help companies avoid costly and time-consuming rework and delays, making them more resilient to disruptions and unexpected events.

By using DFMA to simplify the manufacturing and assembly processes, companies can minimize the risk of defects and delays in production (Ashley, 1995). By creating more reliable and consistent products, companies can build a reputation for quality and reliability, which can help them to withstand unexpected disruptions such as supply chain issues or changes in customer demand.

Another method for reducing risk during product development is to use Prototyping. Prototyping is an iterative process that involves creating a physical or digital model of the product. Prototyping can help to identify design flaws, improve functionality, and reduce the risk of failure (Camburn et al., 2017). By creating a prototype, designers can test and evaluate the product, identify potential issues, and make necessary modifications before mass production. These steps reduce the risk of producing a faulty or suboptimal product. The risks associated with each prototype also need to be assessed quickly and flexibly when working in a Makerspace to ensure that the creators and users of these early prototypes are not exposed to undue risks.

The approaches listed above, FMEA, DFMA and Prototyping all have strengths and weaknesses, and their benefits need to be considered when considering their application to use within a Makerspace. Typically, these methodologies are applied by teams of experts and trained facilitators. However, this pool of expertise is unlikely to be available to a Pacific Island nation developing a product in a Makerspace.

The fourth approach considered for application to Makerspaces for identifying potential hazards and operability problems in a process is HAZOP. The technique also involves a team of experts who review the design of a product or process and identify potential deviations from normal operating conditions that could result in hazardous or undesirable consequences. HAZOP is typically used during the design stage of product development, but it can also be applied to existing processes to identify potential improvements (Dunjó et al., 2010).

One of the primary benefits of using HAZOP in product development is the identification of potential hazards and risks early in the development process prior to construction or manufacture. By identifying potential hazards early, designers and engineers can implement design changes or additional safety measures to reduce the likelihood of these hazards occurring. This early identification can save time and money by avoiding costly design changes later in the development process. This can improve the safety and resilience of the product or process for both consumers and workers.

HAZOP can also improve the quality of the product or process. By identifying potential operability issues, engineers and designers can implement design changes that improve the overall quality of the product or process. These changes can also result in cost savings and improved product resilience by reducing the need for rework or additional quality control measures. The improved resilience provides organizations with an increased capacity to respond to local and system-wide disruptions (Browning et al., 2023).

The focus on reducing risk during product development is essential to ensure a successful product launch and is a common process utilized by large corporations. Failure mode and effects analysis (FMEA), design for manufacturing and assembly (DFMA), prototyping, and hazard operability (HAZOP) all help to minimize the risk of defects and delays in production. By using these methods, designers can identify potential risks, optimize the design for manufacturing and assembly, and test and evaluate the product before mass production (Sun et al., 2022). However, methods that assist the identification and control of risks in smaller organizations have received little attention. There is scant risk management research focussing on controlling the risks associated with the safety of operating in facilities, such as Makerspaces and the risks to end users from the products created within the facilities (Jariwala et al., 2021; Peterson et al., 2022; Wong et al., 2021).

Knowledge about flexible systems that deliver increased resilience is important to Pacific Islands communities. This study provides an overview of using Makerspaces targeting the improvement of system flexibility and resilience where resource scarcity exists by exploring the case study of a risk management process within a Makerspace during new product development.

The next section outlines the research design employed to address the aforementioned research question: How can the risk assessment process be refined to enhance the flexibility of product manufacture in a Makerspace environment with a view to build resilience and meet the needs of the Pacific Islands?

## Research Design

A pragmatic paradigm is employed in this paper; where the purpose of research and inquiry is to benefit human beings dealing with phenomena, they deem important (Coleman, 2015) [see Fig. 1 for an outline of the research design]. Pragmatism rejects the notion of truth and a spectator theory of knowledge (Bernstein, 2010) and instead argue for purposeful knowledge development, and understanding of the consequences of action through practice, discussion, and consensus between individuals to achieve outcomes (Rorty, 1999).

Initially, this research utilized abductive reasoning, derived from pragmatism (Lorino, 2018), to observe and consider the phenomena and explore the literature in order to generate the research question; a form of reasoning extrapolated by Peirce (Peirce et al., 1931) and, more recently, methodologically employed (e.g. Alexander et al., 2014; Eriksson & Engström, 2021; and Settembre-Blundo et al., 2021) and theorized (Sætre and Van De Ven, 2021) by scholars.

Participative action research (PAR) was the selected research design for this study to align with the pragmatic paradigm (Coleman, 2015), focusing on knowledge development through experience, practice, discussion, and consensus. PAR is an approach within the broader methodology of action research (Dickens & Watkins, 1999). Foster (1972) argued that Kurt Lewin's (1946) seminal work on action research was based on the Gestalt; this is, understanding that the contextual experience is as relevant to the study of the phenomena, as the phenomena itself. Moreover, "knowing is developed in relationship between body and the phenomenal world, *through practice*" (Coleman, 2015, p.396). A PAR methodology has utility in research that requires iterative practice and learning processes, centred on the active participation of researchers and non-researchers to explore phenomenon, and determine mutually agreed resolutions to problems (Lewin, 1946). PAR was previously and effectively used in the participative design of frameworks by co-researchers (e.g. Riley-Tillman et al., 2005 and Schulz et al., 2021), utilized to understand and refine current organizational

**Fig. 1** Research design

practice (e.g. Acharya, 2019 and Bhamra et al., 2022) and investigate supply chain issues (e.g. Dadari et al., 2020).

Makerspaces, as previously stated, are environments for learning and continuous improvement of prototypes and PAR's foundations in continuous learning make it an appropriate approach to enrich this research involving the staged development of a flexible risk management framework. within the Makerspace. PAR, as distinct from action research, focuses on the simultaneous dual roles of participants as researcher and subject [termed co-researchers, herein] (Argyris & Schön, 1989); allowing opportunity for co-researchers to explore, refine and reflect on the iterative development within a risk management framework. Such participatory practices promote equity and empowers all participants in the Makerspace community, which can be mirrored in marginalized communities (Freire & Ramos, 2017). The conceptualization of the co-researcher has some correlation with Junker (1952) and Gold's (1958) notion of the observer-as-participant, where the external or outside researcher participates in the field but does not become an "insider", such as was deployed in the study of Elias et al. (2021). However, the PAR methodology seeks to also empower participants as co-researchers in the study. The conceptualization of the observer-as-participant (for the traditional researcher) and co-researchers (for the participants) has clear utility in contexts such as the Pacific Islands where communities are marginalized and face social and economic inequity (Keen & Connell, 2019), particularly in indigenous communities (Germano, 2022).

The current research project required integrating traditional risk management frameworks, such as HAZOP, into multiple plan-act-observe-reflect cycles, thereby learning from the iterations, and consequently developing new iterations from these learnings while not losing the concept of a structured risk management process. This research approach allowed for the refinement of the design, and testing and validation of a structured simplified risk process (SSRP) to ensure it met the objectives of the project. These objectives, according to the identified needs of the Pacific Island nations, included the need for the SSRP to be resource-light, allowed for flexibility in its practical application, and offered a hazard identification process that remained systematic to avoid failures in the hazard identification process (Baybutt, 2015).

Proponents of action research recognize the necessity for dual and simultaneous delivery of academic theorizing and practical application and argue that action research can act as a "bridge" between theory and practice (Zhang et al., 2015, p.169). PAR enables all research participants to act as co-researchers (Schulz et al., 2021) and mutually reflect on changes made because of interventions during the PAR cycles (Gravesteijn & Wilderom, 2018), enabling refinement of the solution and greater commitment to the final results (Argyris & Schön, 1989). Porschen-Hueck and Neumer's (2015) characteristics of participatory research were integrated into the PAR approach; expressly the establishment of reciprocity for all research participants in the (1) co-design of the framework, (2) experiential learning of the traditional HAZOP approach and refinement of an SSRP into a flexible risk management framework, and (3) identification of the interconnectivity of theory and practice. PAR, therefore, had merit in this current research, providing a rigorous, relevant, and previously tested methodological approach that enabled connections between the theories and practices for managing risks when developing products in Makerspaces which are extrapolated in this paper.

To avoid researcher bias, this research clearly defined the case, research design (pragmatic paradigm and PAR methodology) and aligned relevant theory to this design (Yin, 2012). The research consisted of a single, embedded case study (Yin, 2018), of the development of an educational toy in a Makerspace located in Wollongong in the state of New South Wales, Australia. The Makerspace is an appropriate context in which to apply the PAR methodology, for they are decentralized spaces, focused on collaboration and community connection (Sheffield et al., 2017). This is also important in the context of the Pacific Island where indigenous communities participate in community-focused entrepreneurial practices (Cahn, 2008) and Makerspaces, arguably support community-focused practices, helping to "identify problems, build models, learn and apply skills, revise ideas, and share new knowledge with others" (Sheridan et al., 2014, p.505), in keeping with the pragmatic paradigm and PAR methodology. Furthermore, Makerspaces are currently in development in the Pacific Islands; e.g. in Fiji where the Makerspace is designed to support humanitarian aid (Magee, 2019); thus, making the case of the Makerspace relevant to the research paradigm, methodology and applicable to the Pacific Island context.

The current case which was to develop a robot arm educational toy commenced in the Makerspace during 2019 and aimed to produce a commercial product which met associated standards including product risk assessment. The risk assessment methodology chosen for this case study was the HAZOP framework. A single, embedded case study is appropriate when researching a new phenomenon (Yin, 2018), namely the development of a refined, simplified and more SSRP framework within a Makerspace context. The following design elements were developed to address perceived weaknesses of the action research/PAR methodology, namely the focus on problem solving over the development of a broader body of knowledge (Dickens & Watkins, 1999).

From the commencement of the project, a team of five co-researchers were engaged to iteratively develop the flexible framework and triangulate the data from a range of theoretical perspectives; this being critical to the rigour of action research as articulated by Bhamra et al. (2022). Additionally, one co-researcher was engaged to action design improvements that resulted from the HAZOP process. The outcomes of these improvements were part of the data collection phase and contributed to critical reflection, and provide further triangulation of, the data set. The co-researchers were experts in a variety of fields including product design, Makerspace operation, and facilitating HAZOP risk assessments. The team comprised six people who were all employed by a university as shown in Table 1. The research was undertaken between 2019 and 2021.

The PAR incorporated three iterative cycles of plan-act-observe-reflect, with each cycle including the collection of annotated HAZOP templates, reflective observational note taking by each co-researcher, and notes from co-researcher meetings. The three cycles are depicted in Fig. 2. The starting point, stage 1, for the research was the traditional HAZOP framework. This framework acted as the initial delimitation for the participative AR cycle. This framework effectively focused co-researchers' attention on the refinement and evolution of the eventual SSRP. Stage 2 sought to reconceptualize the traditional HAZOP framework within the Makerspace context to improve its agility, while stage 3 applied a risk assessment to the newly developed flexible risk assessment or SSRP to further refine the approach.

The details of each stage of the research are further elucidated in Figs. 3, 4 and 5, demonstrating the cyclical plan, act, observe and reflect process undertaken in each stage.

## Results

The outcomes for the participative action research can be best described by three main cycles where artefacts were produced. The first cycle artefacts were those created using a traditional HAZOP process, the second cycle was an attempt to conceptualize an improved application of HAZOP within a Makerspace environment, and the third cycle was an integration of an SSRP in a risk management framework and prototyping to produce a tool which contains the rigour of a HAZOP with the connotations of flexibility suggested by Sushil (1997).

**Table 1** The roles and position of the co-researchers developing a flexible HAZOP framework

| Name | Role/Position |
|---|---|
| Participant 1 | Makerspace Manager/ Designer |
| Participant 2 | Lecturer |
| Participant 3 | Director Makerspace/ Designer |
| Participant 4 | Makerspace Designer |
| Participant 5 | HAZOP Facilitator/ Lecturer |
| Participant 6 | HAZOP Scribe / Lecturer |

### Traditional HAZOP Process

The first PAR cycle involved following the traditional HAZOP process. The planning and action for the PAR cycle were the same activities used for the HAZOP process and included the identification of risks that could be associated with the robot arm educational toy. The reflection of the HAZOP process resulted in the systematic identification of product risks requiring action and resulted in the subsequent redesign or development of counter measures. These were captured in a HAZOP study report. Once the HAZOP process had concluded, the PAR cycle included another aspect of reflection where the effectiveness of the HAZOP process in the Makerspace environment was considered. The process was thought to have successfully contributed to an improved design and a safe product for consumers, however, three significant issues did emerge. The first issue related to the timing of the HAZOP process. It was considered that if a risk review had occurred earlier then some design issues could have been more effectively resolved during earlier stages of product development. Secondly, the static nature and high level of resources needed to conduct the HAZOP process meant that the risk review would likely be conducted only once. This realization introduced a dilemma as to when was the best time to conduct a HAZOP and whether multiple revisions were necessary if it was conducted too soon. The HAZOP process was originally intended to be used once the design was completed but this meant that design flaws could be overlooked and lead to the development of a multiple step process for HAZOP (Kletz, 1997). This flexible application of the HAZOP concept has been applied in this research. The third issue involved the scarcity of adequately trained facilitators in a Makerspace environment. Risk management facilitators are usually trained and employed by large organizations or consultancies. HAZOP facilitation is typically associated with large scale manufacturing plants with significant process plant operations. The HAZOP facilitators are usually highly trained bachelor's degree engineers who have completed an additional 5 days of intensive training in HAZOP facilitation. Although the investigation team was fortunate to have two trained HAZOP facilitators on the project, it was unlikely that a Makerspace and its associated maker community would have access to such

**Fig. 2** Participative action research cycles

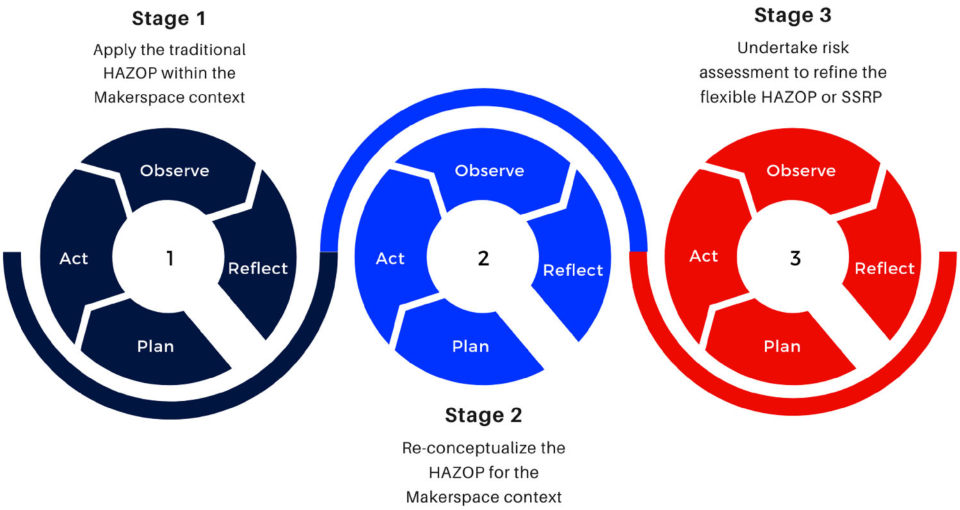
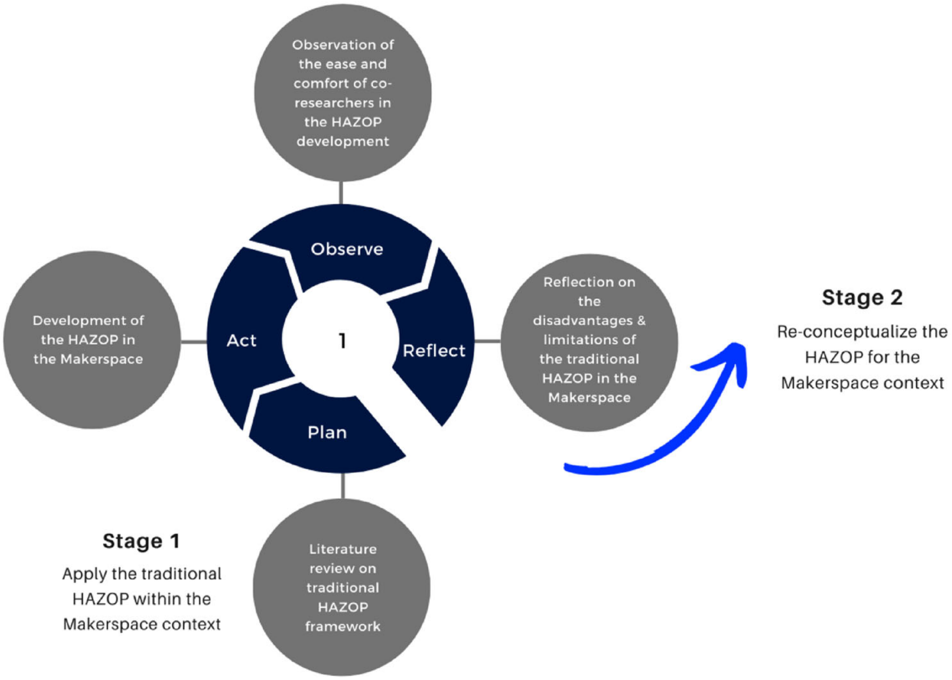


**Fig. 3** Stage 1 PAR: Application of the traditional HAZOP within the Makerspace context



resources in its normal operation. These limitations to the Makerspace community would also most likely apply to Pacific Island communities where access to resources and education has been identified as ongoing challenges (United Nations, 2020).

## HAZOP Within the Makerspace Environment

The second PAR cycle involved an attempt to reconceptualize the HAZOP process to address the resource scarcity and other issues found in the first PAR cycle. This cycle was undertaken by adapting the traditional HAZOP processes, by adaptation of guidewords and process deviations, to reflect the key value adding steps in the design of a prototype in a Makerspace while retaining the detailed systematic approach of a HAZOP. Consideration was also given to presenting the information so that a typical person in a Maker community would be able to use the process. A risk management framework (Fig. 6) was then constructed from the investigators' experience of what was believed to be useful in terms of reasoning and actions taken in the HAZOP of the Robot arm. The risk management process was divided into risks that manifested before and after development of a prototype and grouped into design process and testing process risks. This was inspired by the concept of a bowtie diagram which looks at controls that are put in place before and after a central event (de Ruijter

**Fig. 4** Stage 2 PAR: Reconceptualization of the HAZOP for the Makerspace context

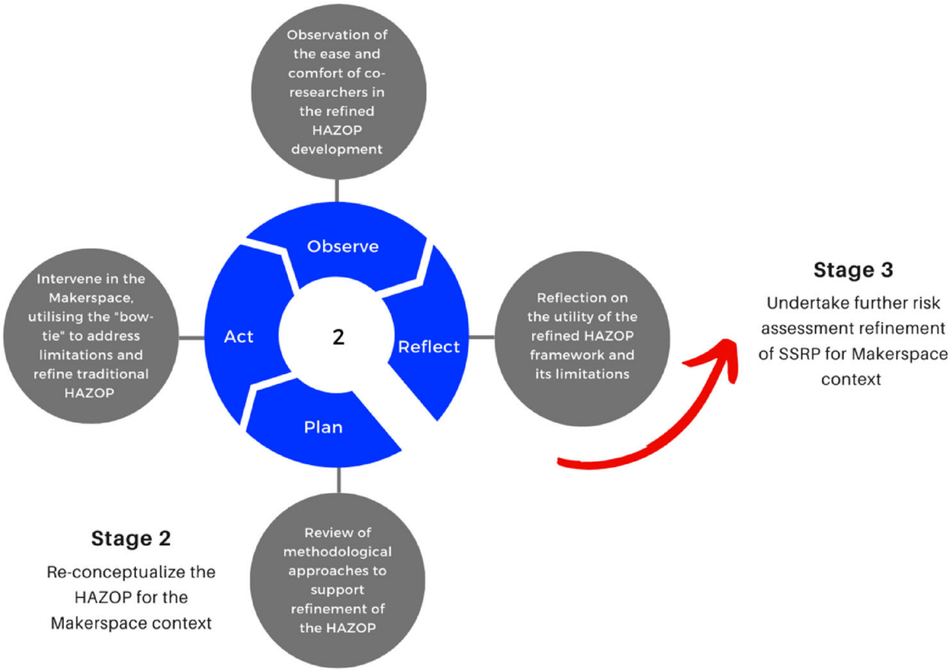
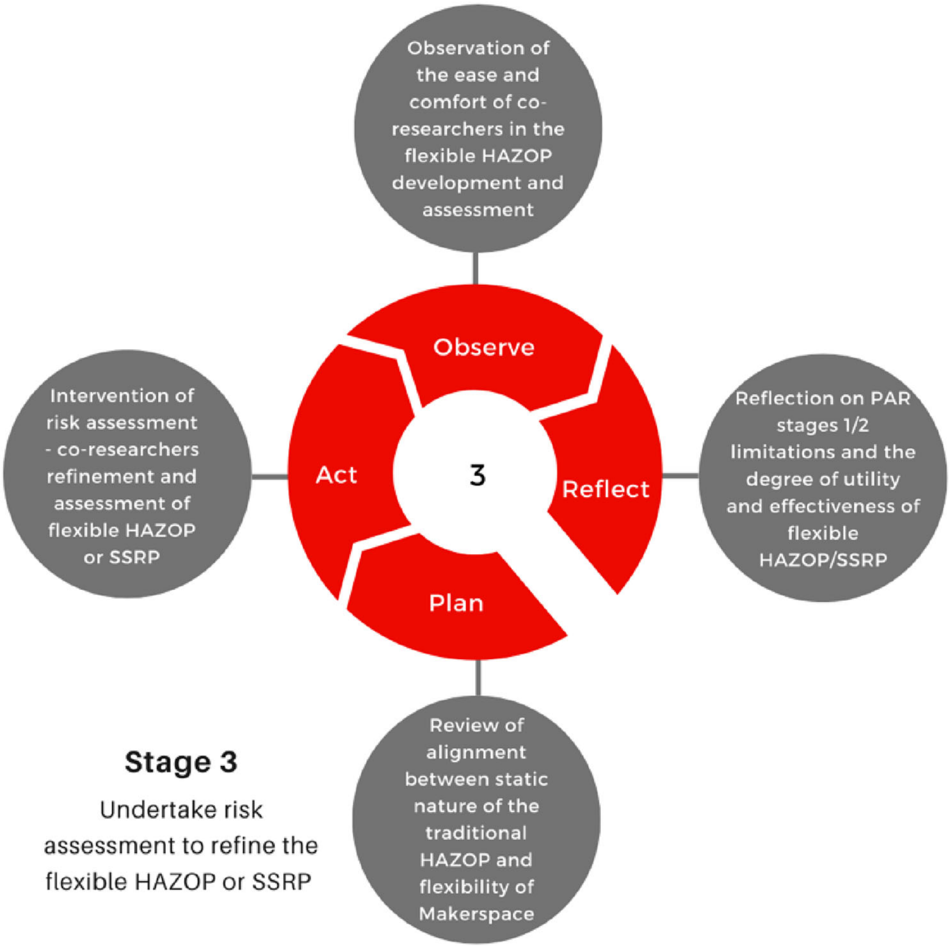


**Fig. 5** Stage 3 PAR: Risk assessment to refine the flexible HAZOP or SSRP



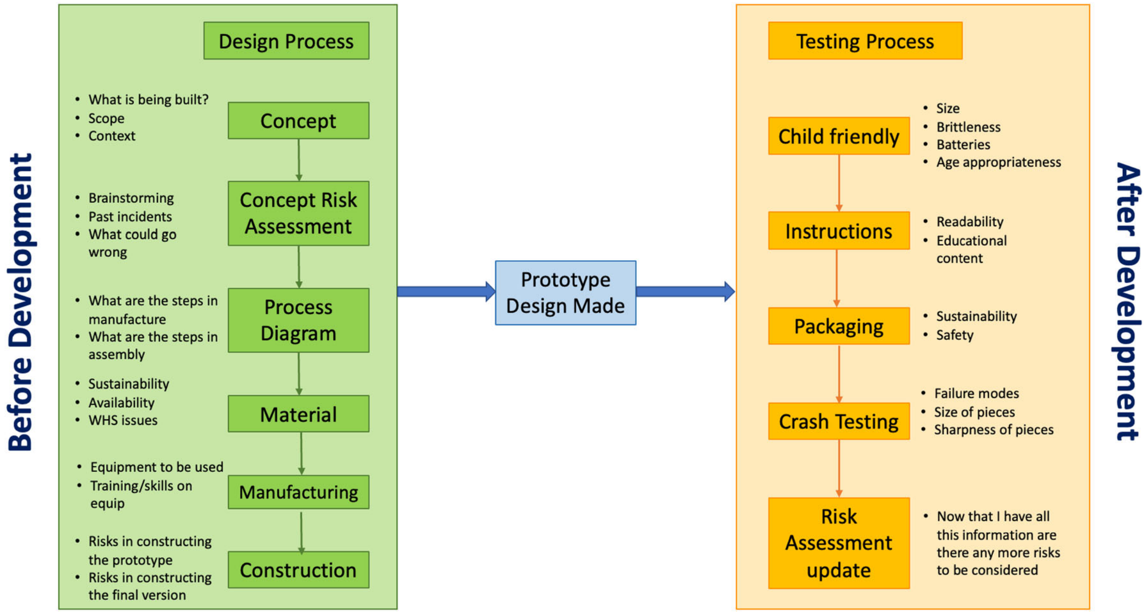


**Fig. 6** The first conceptualization of a simplified risk management framework that may be useful to Makerspace users who want to develop educational toys

& Guldenmund, 2015). In this case the central event is the creation of the prototype.

The HAZOP process guidewords for identifying hazards were modified and simplified for the Makerspace context. This was accomplished by disaggregating the design and testing processes into parts where unmitigated risks may exist. Additional prompts, based on the development of prototypes in a Makerspace, were then added for each guideword to assist a risk management framework user to discover any unidentified risks.

On reflection of progress made towards a risk management framework for use in a Makerspace, it was realized that the static nature of the HAZOP process, even when paired with a bowtie diagram, still did not provide the flexibility around redesign and continuous improvement of prototypes throughout the design process. This inflexibility produces a dilemma around when to conduct the risk assessment to ensure safety and design integrity which still needed to be addressed. Should the tool be applied after the development of the first prototype or after the final design is completed? The investigation team decided that it was important to capture the concern that actions taken to innovate the design could introduce new risks and that a broader risk management process should be undertaken as an iterative rather than static undertaking in the Makerspace environment. The risk management framework was adapted, as shown in Fig. 7, to address this concern. This same concern would be applicable to designing or adapting assets or processes in a low-resource environment. The aim of this tool should be to have a flexible process that can easily be applied to changes and alteration to designs or processes. By identifying problems before design solutions are implemented risks can be reduced. This concept is applicable to situations in Pacific Island communities where changes due to post-pandemic events may need to be assessed quickly and rapidly to ensure that risks have been considered. By considering risks prior to the application of changes, the resilience of the community will be increased through reduced rework and redesign of assets and processes.

Further reflection by the investigation team unearthed a concern that the adapted risk management framework was not flexible enough and did not follow the way in which designers in the Makerspace worked. This process did not clearly include the possibility that the original design intent may need to be changed as more was learnt about the design that was being built. The arrows did not convey the natural flow of reasoning that would occur within a Makerspace environment. For example, the arrows in the design process implied a linear flow from concept to construction that is rarely the case and does not reflect the adaptability and flexibility of the prototyping process. One of the key strengths of a Makerspace is that the utilized technology allows for agility in exploring new creative ideas through rapid prototyping. It became apparent to the team that the adapted risk management framework needed further refinement to be more flexible and align with the iterative nature of the product development prototyping activities in the Makerspace environment.

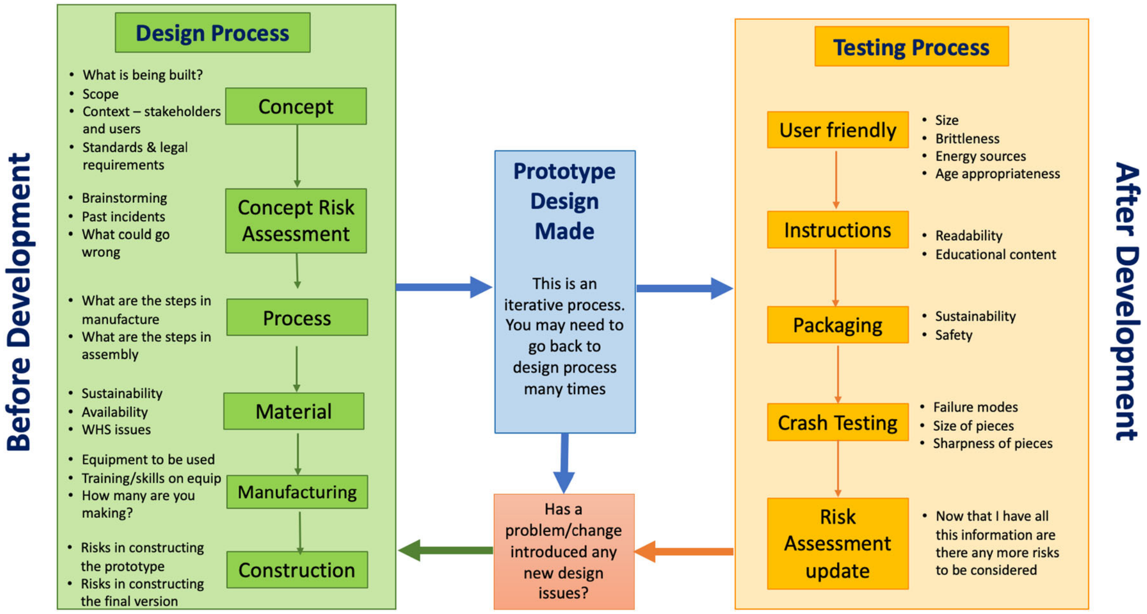


**Fig. 7** An adaption to the simplified risk management framework for Makerspace users wanting to develop educational toys which introduces an iterative approach

## Integrating Risk Management and Prototyping

The third and last PAR cycle aimed to integrate the iterative nature of prototyping into a refined risk management framework. The plan was to disaggregate the experience from the first PAR cycle and then introduce modified HAZOP guidewords differently to the second PAR cycle. The focus of the disaggregation and reconceptualization to align the risk management process with the prototyping activity to incorporate the iterations associated with the product development in the Makerspace environment. The outcome of the reconceptualization is a Makerspace product development risk assessment process or PDRAP as shown in Fig. 8. It comprises three phases which include idea development, prototype development, and product testing.

The idea development phase incorporates risks associated with concept design and proof of concept. If the idea is believed to be feasible, the maker is then able to progress to the next phase which is prototype development. In this phase the iterative nature of product development is encapsulated with risks associated with materials, manufacture, construction, and process identified. With each prototype iteration, an assessment on the functionality of the product under development is appraised. If the product is not functional, then the proof of concept is revisited and if feasible, another iteration of the prototype development occurs. This cycle continues until the product under development is deemed functional. When this occurs, the maker can move to the third phase which is product testing. During product testing, risks associated with crash testing, end user friendliness and safety, instructions, and safety are explored. Changes to the design or risk mitigation actions are undertaken for any risks that are identified that may lead to an unsatisfactory end user experience. Any changes made are then reviewed to ensure the design is adequate. If new problems are introduced into the design, then the maker returns to the prototype phase until the induced problems are overcome. If the review is unable to identify any uncontrolled risks relating to the design, then the risk assessment process is complete. The product is considered ready for market testing or product launch.

Reflecting upon the product development risk assessment process (PDRAP), the investigation team considered that the concerns uncovered in the first and second PAR cycles had been addressed. This reflection and decision were considered collaboratively by the co-researchers and was reached through consensus; a key component of the PAR approach and highly relevant to the Pacific Islands context where community is central to decision-making. The dilemma around the timing of the HAZOP process and if multiple risk assessments were required had been addressed by the proposed three phase risk assessment process. Each phase capturing the important risk assessment considerations that may be present in that phase and eliminating the need for multiple risk assessments. The prototyping phase having risks assessed in an iterative manner as changes are implemented.

It is interesting to note that while the PDRAP is effectively a risk assessment that is based on the premise of a systematic HAZOP approach with guidewords and deviations, the person undertaking this review may not even

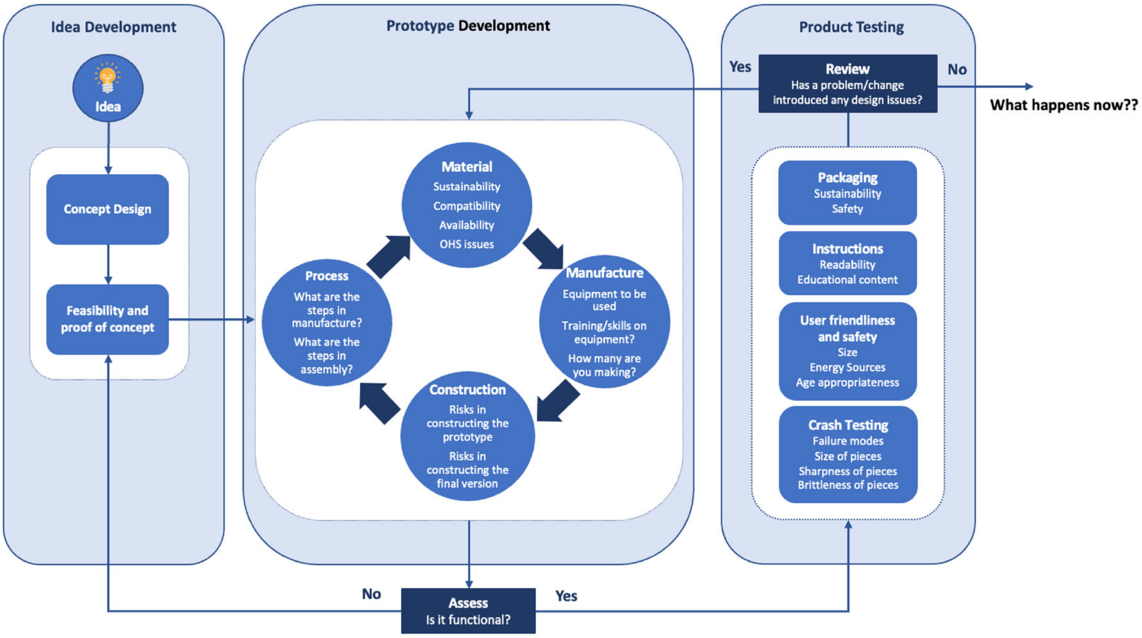


**Fig. 8** Makerspace Product Development Risk Assessment Process (PDRAP) as conceptualized by the investigation team

realize that they are using processes based on advanced risk management techniques. The term risk is only used twice in the PDRAP and refers to construction risks which could be linked to the DFMA considerations.

The resultant PDRAP was considered an SSRP, having met the needs of the Makers in the investigation team and aligning with the rapid prototyping that occurs in Makerspaces. The flexibility of the risk management system allowing for makers who are untrained facilitators to identify and control product risks through development. The management of these risks allowing for a higher level of resilience to be achieved for the product under development, which in this case was the Robot arm educational toy.

### Applicability to Pacific Island Communities

What this case study has shown is that the principles in sophisticated risk management tools such as HAZOP and bowtie diagrams can be adapted to be used in simplified yet rigorous ways to support people trying to manage risks without an in-depth knowledge of risk management principles. This has potential benefits in reducing time delays and wastage during small-scale manufacturing, which is particularly important for communities seeking to adapt during natural disasters, because of external challenges. Similarly, wastage reduction has high utility for communities suffering from existing low resources. It also demonstrates that further participative action research cycles may be used to further refine risk management for specific contexts. Further, the utilization of participative action research and the Makerspace has a potential high degree of synergy with regional communities that value connection to community, such as the heterogeneous communities of the Pacific Islands. Therefore, this same process can be applied to people in Pacific Island communities, whom like people in Makerspaces everywhere, are trying to develop new and better ways of doing things. The use of tools that support the efforts of people to reduce the risks by asking simple questions in a rigorous, yet flexible manner, can only support the efforts of people to improve the resilience of their communities.

## Discussion

The motivation for this paper is to improve the lives of Pacific Islands people through sharing knowledge revealed about risk management in flexible systems for product resilience from the case study. The case study takes place within a Makerspace which offers access to a space that enables community engagement and a space for problem solving and knowledge sharing while utilizing limited resources, like the Pacific Island communities, where community is a focus and resources are limited for new product develop. The experience gained from the participative action research that informs the case study and answers the research question, provides the researchers with valuable insights into how resilience may be improved when a risk assessment process is refined to enhance the flexibility of product manufacture in a Makerspace environment. These advances in our understanding of flexible systems and resilience are important for Pacific Island people who may need to adapt supply chains from a global to regional focus. Embracing new product development and the emerging manufacturing technologies found in Makerspaces make rapid prototyping and small-scale production viable which can support Pacific Island people in facing present and future disruptions and challenges.

There are potential benefits and latent value in leveraging off the benefits of a Makerspace while utilizing a participative action research approach. The study found that Makerspaces are suitable contexts for the adaptation of sophisticated systems by harnessing the iterative utility of PAR. The literature highlights how Makerspaces and PAR encourage participant learning and cooperative decision-making (Giannakos et al., 2017; Lewin, 1946) which was similarly found in this study. Leveraging the benefits of the Makerspace and PAR, has the added potential benefit of increasing the training capacity of co-researchers (utilizing the parlance of the PAR methodology employed in this study) where co-researchers learn from each other, through the iterative process of PAR and from the resources available in the Makerspace. In environments like the Pacific Islands, where access to education is a significant issue and resources are low (United Nations, 2020), the Makerspace/PAR assemblage has potential value to provide low-cost, regional spaces for training that continue to support connection to community.

The use of risk management and the HAZOP process to improve the resilience of the new product development of an educational toy provided some interesting insights into the issues facing resource limited people when using a process usually employed by mass producing corporations. Issues that arose included limited access to trained facilitators, dilemmas associated with the best time to undertake activities, and having to continually adjust for the difference in process context. The effectiveness and efficiency of the process were adversely impacted in the Makerspace environment although satisfactory risk management could be achieved. Taking the opportunity to reconceptualize the risk management approach to overcome these challenges, in a Makerspace environment, provided the conditions needed for the development of the product development risk assessment process (PDRAP) which is the major outcome from this study.

The PDRAP furthers literature in the areas of flexible systems and resilience through several contributions. Firstly, it demonstrates that risk management approaches used in large organizations can be reconceptualized into more suitable processes for organizations with limited resource. The alternate process is improving system flexibility and delivering comparative levels of operational resilience, supporting prior research (Carvalho et al., 2012; Khorasani, 2018). This contribution also extends flexible systems management theory with the decoupling of constraints to empower Pacific Island people with choice (Sushil, 1997) to respond quickly with manufacturing solutions to meet their changing needs (Christopher & Peck, 2004; Shukla & Sushil, 2020). Second, the PDRAP is an example of a risk management process that can be used to improve product design and support design for adaptability which is advocated by Browning et al. (2023) as an important aspect for safeguarding supply chains from system wide disruptions. Third, the development of the process demonstrated the enabling role that Makerspace environments have in the creation of processes that are effective in low-resource environments. An innovation role Makerspaces typically undertake are the rapid prototyping of products (Sharma, 2021). Lastly, the PDRAP provides low-resource environments, such as Pacific Island communities, with an effective product risk management tool that can be applied to emergent manufacturing activities to improve safety and reduce rework and redesign. These activities may take place in Makerspaces or other configurations of manufacturing assets which are employed to move global supply chains into regional areas or recover from natural disasters.

As with all research, this study has limitations. The findings of the participative action research pertain to the case of a Makerspace in a higher education environment. Methodologically, the pragmatic paradigm, coupled with the PAR methodology could be challenged for the potential lack of theoretical contribution, however, theory, Susman and Evered (1978) argue, is developed through practice (in this study: iterative cycles of PAR within the Makerspace context), and assessment of the outcomes (through collaboration and decision-making of the co-researchers, utilizing existing theories (flexible systems and resilience). Notwithstanding, further research is required before the findings may be used for generalized application. Additionally, co-researchers, in the current study, were not of a Pacific Island background. It would be highly appropriate and practically useful for interested Pacific Island communities to apply the methodological approach within their contextual environment to further enhance our burgeoning understanding. Also, the conceptualized process was only tested on the manufacture of an educational toy. Although the conceptualization was carried out with the intention of being independent to the product developed, there may be unintended salient issues. Further research is required to understand the effectiveness of the PDRAP for different products in different environments. Additionally, while this process has been considered for use in Pacific Island communities, the real-world application of this is yet to be tested.

## Conclusion

The conceptualization of a more flexible product development risk management process has provided an alternate pathway to effectively innovate products in low-resource environments. The resulting improvement in system flexibility supports the building of resilience in areas of the world such as the Pacific Islands where the reconfiguration of resources has become necessary due to supply chain disruptions from national strategic decisions and the increased prevalence of natural disasters and other external challenges following the COVID-19 pandemic. The extension and application of flexible systems theory into a low-volume product development environment benefits Pacific Island people. Those using digitized manufacturing technology can mitigate the associated process, product, and end user risks. The positive impact of this contribution is both the manufactured products are more resilient functionally and the local manufacture of products for resilience-building activities becomes more viable. The PAR methodology used in this research is also valuable, although perhaps, less tangible. Pacific Island people wanting to further their agency over resilience-building activities are provided with an approach to adapt conceptual frameworks from differing cultures and personal value systems to the Pacific Island context. This includes refinement of the PDRAP to further align with the context of a specific nation. Pacific Island communities, seeking to enhance small-scale manufacturing at a regional level that is highly flexible, characterized by low resourcing, focused on community collaboration and collective decision-making, may further their aspirations by pursuing the utilization of flexible systems, Makerspaces, and participative action research to support resilience-building.

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### Declarations

**Conflict of interest** The authors have no competing interests to declare that are relevant to the content of this article.

**Disclosure** The authors have no relevant financial or non-financial interests to disclose. All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript. The authors have no financial or proprietary interests in any material discussed in this article.

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## Key Questions Reflecting Applicability in RealLife

1. Where else may a flexible systems approach drive lower levels of risk for improved resilience?
2. How may Makerspaces continue to develop technological solutions for recovering from disasters in the Pacific Island region?
3. Can the use of the action research methodology assist in adapting risk approaches for service-based Pacific Island resilience activities?

**Adrian Tootell** is a management academic and professional. His career has spanned both academia and industry where he has developed and shared theory and applied knowledge relating to product development, quality, systems, and operations management. His knowledge and experience were utilized in leading and supporting the review of Supply Chain Management curriculum, national and international standards. He received his PhD from the University of Wollongong in 2017 for his work on initiating and developing innovation relationships between universities and industry. This has driven a continued interest in utilizing the translation of science for advanced manufacturing technology. As an Honorary Fellow of the University of Wollongong, Adrian continues to explore his research interests while employed and contributed to industry-led projects in the manufacturing, defence, and aerospace sectors.

**Leanne Treadwell** is a risk management specialist with over 30 years of experience in occupational health and safety (OHS) across diverse industries which include heavy manufacturing, IT, transport, security, and aged care. Having served as a safety manager, regulator, and consultant, she brings a wealth of practical knowledge. Leanne's research focuses on the application of tools and systems to enhance OHS objectives and reduce harm in workplaces. Since 2008, she has been a lecturer in the occupational health and safety academic programme at the University of Wollongong. Leanne's commitment to advancing OHS extends beyond her academic role, reflecting her dedication to creating safer work environments through research, education, and practical insights. Her influential contributions make her a respected figure in the field, driving positive change in workplace safety.

**Rebekah Schulz** an academic and former industry practitioner, achieved her PhD in Business from the University of Wollongong in 2020, specializing in the co-production of performance indicators for cultural facilities in public administration. As a senior leader in the public sector, Rebekah served most recently as the Director of Community and Culture at Georges River Council, enhancing community engagement and diverse programme development. Transitioning from a successful 20-year career in government, Rebekah assumed the role of Lecturer at the University of Wollongong's Faculty of Business and Law in 2022. Driven by a commitment to continuous improvement, Rebekah's current research focuses on learning and teaching within the university context, specifically exploring feedback literacy, critical reflection, and participative action research. With an enduring interest in public administration, she continues to contribute to the fields of women in leadership, community engagement, and ethical governance.

**Belinda Margetts** is a qualified Chemical Engineer with over two decades of experience, in process engineering design, manufacturing operations, tertiary teaching, and technical risk management. As a multifaceted professional, Belinda is adept at blending her broad knowledge with confident leadership. She brings a pragmatic approach to strategic problem solving, emphasizing the human element in understanding motivations. Belinda is recognized for her ability to bring people together, engaging them in discussions on complex and challenging topics often avoided by others, and unifies diverse individuals into collaborative teams. Belinda Margetts epitomizes the integration of technical expertise, leadership, and a deep understanding of human dynamics, making significant contributions to both academia and industry.

**Jessica Grozdanov** is a multifaceted professional, adeptly blending roles as a Manager, Engineer, and Research Assistant. With a robust skill set and diverse expertise built upon her engineering background, Jessica seamlessly collaborates with academic and industry peers across the education, medical, business, and technology domains. Her comprehensive knowledge and hands-on experience extend to the operational intricacies of Makerspaces, where she serves as a collaborative manager who invests in mutually beneficial outcomes. Jessica actively contributes to interdisciplinary projects, showcasing her prowess in both quantitative and qualitative research methodologies. Her passion lies in integrating emerging technologies into the fabric of everyday life for the broader community. As a forward-thinking individual, Jessica is committed to advancing the nexus between technology and society, ensuring its positive impact through innovative solutions and meaningful collaborations.

**Geoff Spinks** received his PhD from the University of Melbourne in 1990 for his work on the mechanical behaviour of polymers, and he has maintained a research interest in this area specializing in mechanical actuator materials (artificial muscles). Geoff is currently Senior Professor and Head of School in the School of Mechanical, Materials, Mechatronic and Biomedical Engineering at the University of Wollongong (UOW), Australia. Geoff is also the founder of UOW Makerspace. Geoff has had a strong engagement with teaching across all levels of engineering materials and was co-founder of UOW's bachelor degrees in nanotechnology. His current interests include new product development and new manufacturing methods (such as 3D printing) that utilize his artificial muscle materials.