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Design and development process for a novel technology capable of providing a new breaking force attenuating sports surface.

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Abstract

Lower limb loading rate is a major contributor to athletic injury because it represents the stress being absorbed by an athlete's lower limbs that makes them vulnerable to stress fractures, as well as knee and ankle joint injuries. This research therefore sought to identify a means by which lower limb loading rates could be reduced and therefore the risk of overloading injury reduced. A sports surface that encourages elastic deformation during contact in both the horizontal anterior-posterior direction and the horizontal medial-lateral direction through a process of horizontal deformation and displacement may result in reduced foot and limb loading. This surface should maximise horizontal energy attenuation in order to reduce the risk of injury while at the same time provide satisfactory energy return to avoid player fatigue.

Effective product research and development methods centre on the ways in which the activities can be effectively planned, controlled and implemented. The process can be regarded as a sequence of activities and decisions which progress a problem solving process from the initial identification of the problem, through to a final implementable design solution. The process of design is fundamentally an iterative method, which comprises the articulation of the problem which is to be solved, collecting and codifying pertinent information, the divergent exploration of potential problem solutions, convergence towards a favourable solution, and finally, the detailed implementation and optimisation of the design solution.

The creative process followed, has resulted in the design of a novel, and commercially improved modular plastic tile sports surface system. This has been realised through the development of an innovative, sustainable, shock attenuating tile and connector geometry, which aims to reduce braking forces on the sports surface to acceptable levels, and thus reduce the risk of athlete injury. This research is significant as currently no sports surface exists which specifically targets horizontal force reduction, as a means to reduce injury rates.

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Keywords:

1. Introduction

Prior research indicates that the magnitude and repetitive nature of the high braking forces experienced while an athlete starts, stops, turns and lands on a sports surface, contributes to the incidence of lower limb injury (Steele and Milburn 1987). Research also indicates that horizontal ground reaction forces experienced by an athlete during competitive play, can be even higher than vertical ground reaction forces (Steel and Milburn 1988). The ever-changing nature of sports and the desire to play different sports in many different climactic conditions, has led to sports being played on synthetic surfaces in opposition to natural surfaces. In recent years, there has been a trend towards the construction of multi-sport facilities, where sports facility utilisation

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is optimised by offering a multitude of different sports, such as netball, basketball, indoor soccer, volleyball, inline hockey and martial arts, all being played on the same sports surface.

Therefore, sports are now increasingly played on a variety of point elastic multi-layer synthetic sports surfaces. Sports surfaces can therefore be highly complex structures, often constructed from many elements which contribute to their compound behaviour. Despite such a wide range of playing surface types, the literature states that there is a lack of data connecting the suitability of the playing surface, to the performance characteristics required for various sports. Conventional 'sprung' sports surfaces primarily attenuate vertical ground reaction forces (VGRF) as they can only displace vertically. This dampening effect reduces the energy being returned vertically to the athlete, thus preventing limbs from being overloaded and protecting them from injury. This is perfectly satisfactory when an athlete is stationary, and landing on the surface from a static jump. Playing sports and other forms of physical activity however in many instances, require an athlete to travel over a sports surface at high speed.

Prior research concluded that interconnected modular tile sports surfaces such as that shown in Figure 1, have the potential for inadvertent independent lateral displacement under the application of load, and can potentially dissipate more breaking force than a homogenous sports surface (Bagley 1992; Walker and Subic 2010).

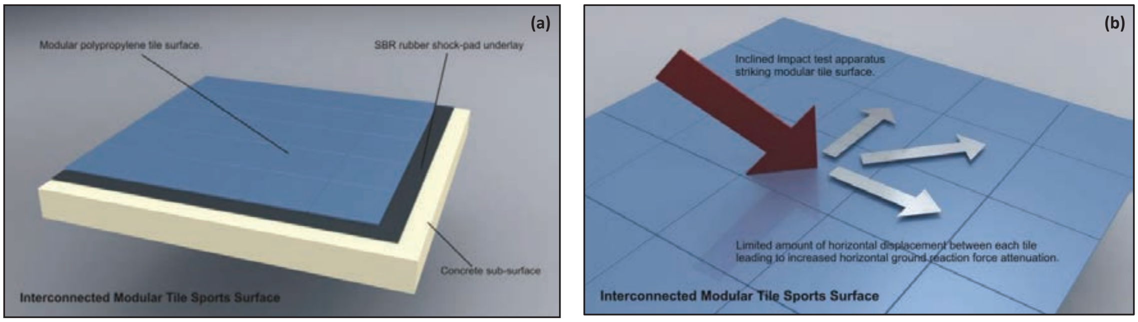

Fig. 1. (a) Interconnected modular tile sports surface, with rubber shock-pad underlay, (b) Horizontal displacement under combined horizontal and vertical load.

This paper discusses a new sports surface development process, employed to design a novel modular tile sports surface which specifically targets combined Horizontal Ground Reaction Force Reduction (HGRFR) and Vertical Ground Reaction Force Reduction (VGRFR), from design brief, research and product definition development, through idea generation, concept development, analysis, prototyping and testing and onto final concept development.

2. Method

The design exercise was structured and conducted within a Stage Gate framework, focusing on problem research, concept development, prototype development and testing, product finalization, documentation and commercialisation. Each of the design process phases consisted of smaller sub-stages that allowed detailed user centred research to be undertaken as articulated in Figure 2, by observing users within a sports facility environment and seeking expert advice on the many iterative prototypes that were developed, from key project stakeholders.

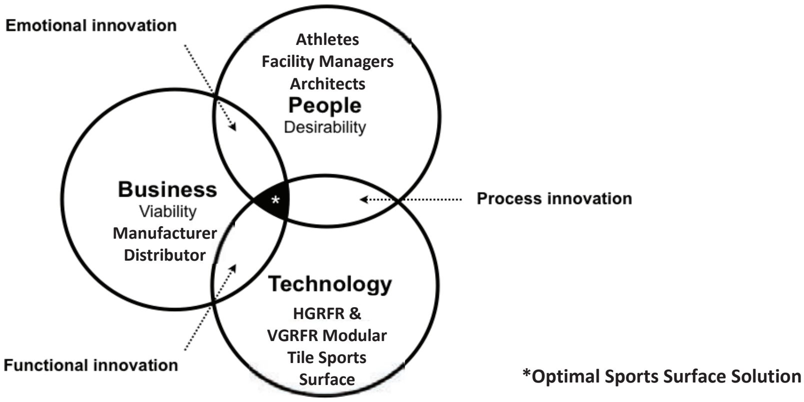

Fig. 2. User centred sports surface design process

3. Development process

Effective product design and development methods centre on the ways in which R&D activities can be successfully planned, managed and executed. The process can be viewed as an arrangement of synchronized activities and decisions which progress the product development process from initial problem identification, through to a final detailed problem solution. The process of design is fundamentally an iterative methodology, which includes the expression of the problem which is to be solved, researching, collecting, codifying and analysing information, the application of creative thinking approaches, and the exploration of potential problem solutions through prototyping and testing and finally implementing an optimised solution. During the product development process, it is essential to differentiate between different categories of prototype and test that can be applied at different stages of the new product development process. This method assists designers consider the intent of each prototype developed. Alternative prototyping and test methods have different purposes, methods and categories of simulation:

- Exploratory surface prototyping and testing
- Assessment surface prototyping and testing
- Validation surface prototyping and testing
- Comparison surface prototyping and testing

A typical new product development method will normally, consist of multiple phases, as detailed in Figure 3. The process is normally represented diagrammatically with overlapping phases, to illustrate the iterative character of the product development process (Cooper 2005).

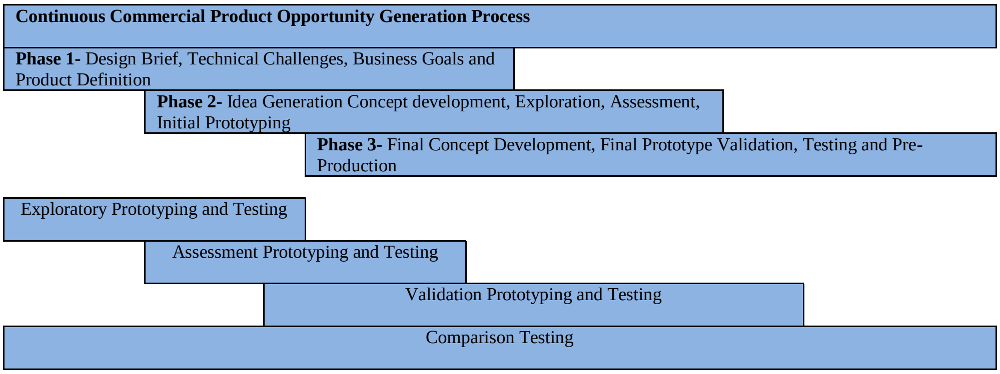

Fig. 3. Exploratory, assessment and validation prototyping and testing stages

It is vitally important that sports surface prototypes are continually evaluated and screened against usability metrics, to ensure that only concepts which meet user expectations, advance to the next phase. Over the entire design process, iterative functional flooring prototypes were simulated, constructed, tested and evaluated by stakeholders, leading to the final sports surface design which was eventually adopted.

3.1. Phase 1: design brief, research, and product definition development

Also known as the project-feasibility stage, the first phase of the new product development process aims to establish the commercial and technical feasibility of a project and establish measurable criteria for success. This phase necessitates a broad understanding of the needs and desires of potential users and customers, the environment and conditions of use and the benefits which will be conveyed to users by a new sports surface. The primary output from this phase is normally a comprehensive product definition or product specification, which describes the desired attributes of the new surface, in addition to a clearly articulated business case to validate any required financial investment.

This phase of the methodology seeks to:

- define in detail the design brief and the problem which is to be addressed and the conceptual vision for the project
- identify aspects of required key functionality and sustainability requirements
- describe the sports surface market and the competitive environment for a new surface
- determine the anticipated sustainable competitive advantage for the new surface
- identify the customer’s safety performance requirements
- calculate the surfaces life-cycle costs
- ascertain the technical challenges which will be addressed by undertaking the project and product definition.

The aim of the project was therefore to develop a conceptually new sustainable sports surface, which has the capacity to reduce the number and severity of injuries resulting from player/surface interaction. The research also sought to improve athletic performance while reducing the likelihood of injury. Surface benefits would include:

- increased levels of sports participation and enjoyment of sport
- reduced period and type of sports injury treatment required
- less time lost through injury
- reduced risk of giving up sport through injury
- reduced environmental footprint in comparison to other surfaces currently available in the Australian, North American and European markets

Figure 4 details the ten major definition criteria with associated sub-categories, which should be taken into consideration when determining the performance requirements of a new sports surface. The criteria were established after detailed interviews with the project's stakeholder groups.

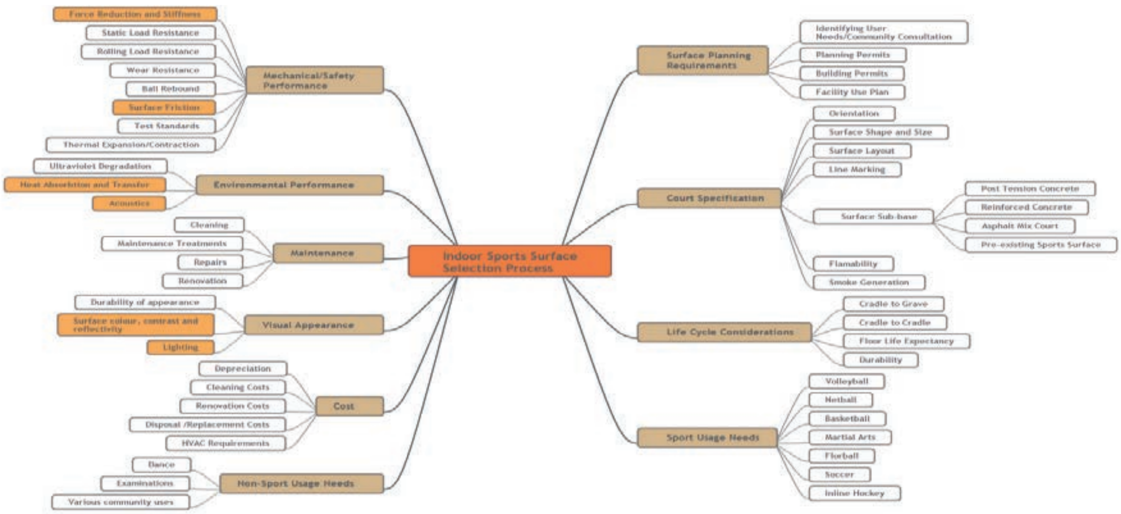

Fig. 4. Indoor sports surface selection criteria (Walker and Subic 2010)

Although all surface selection criteria were considered during the design process, as the primary focus of the design task was principally to minimise injury and maximise environmental performance and surface economics, the product definition was centred on:

- multipurpose/multi-sport use (sporting and non-sport (community) usage needs)
- mechanical/safety performance (horizontal and vertical force reduction)
- environmental performance (minimisation of materials & energy consumed and waste and emissions generated, over the surface's life and the adoption of 'cradle to cradle' environmental strategies)
- life cycle cost considerations (including 'cradle to cradle')

3.2. Phase 2: Idea generation, concept development, analysis, initial prototyping, testing and selection

Having specified the target product opportunity and having defined the desirable attributes of a successful sports surface solution as detailed in the product definition, the conceptual design phase aims to generate multiple divergent sports surface design concepts, describing potential future surface solutions. During this phase, product architecture and usability issues are established and a range of processes are explored with creative approaches developed, relating to the established product definition. Specifically, function analysis, peeves analysis, market segmentation, customer benefits analysis and sustainable design approaches were all considered.

Customers not only want sports surfaces which are reasonably priced, but they also require sports surfaces which are useful, that function as promised, are usable, desirable, well differentiated from competing surfaces and sustainable. In addition to these customer-oriented requirements, the manufacturer requires a surface which is easy to produce and profitable.

3.3. Phase 3: Final concept development, final prototype testing and pre-production

Conceptual filtering is then applied within the design process to determine which of the various emerging development concepts best satisfies the product definition/specification established in Phase 1. Once a dominant approach has been identified, it must be developed into a manufacturable and commercial reality. This aspect is usually one of the most time consuming phases of the design process, as high-fidelity prototypes and production tools may be required. It is therefore critical that the concept does not diverge too far from the agreed product definition, since detailed engineering and design decisions will subsequently be made.

Phase 3 of the design process sought to explore a range of processes which enable creative thinking approaches in answer to the product definition and validation testing. Specifically, this phase addressed design for manufacture, failure modes and effects analysis, morphological analysis and unit cost analysis. The developed ideas were interpreted and analysed in a mind-mapping format (Buzan and Buzan 1996) as shown in Figure 5, and the ideas presented in the yellow sections below, were those initially selected for further development. The total number of combinations was very large, therefore those displayed, were limited to the most technically feasible, environmentally sustainable and commercially attractive options. User need issues identified during the peeves analysis were also considered during morphological analysis.

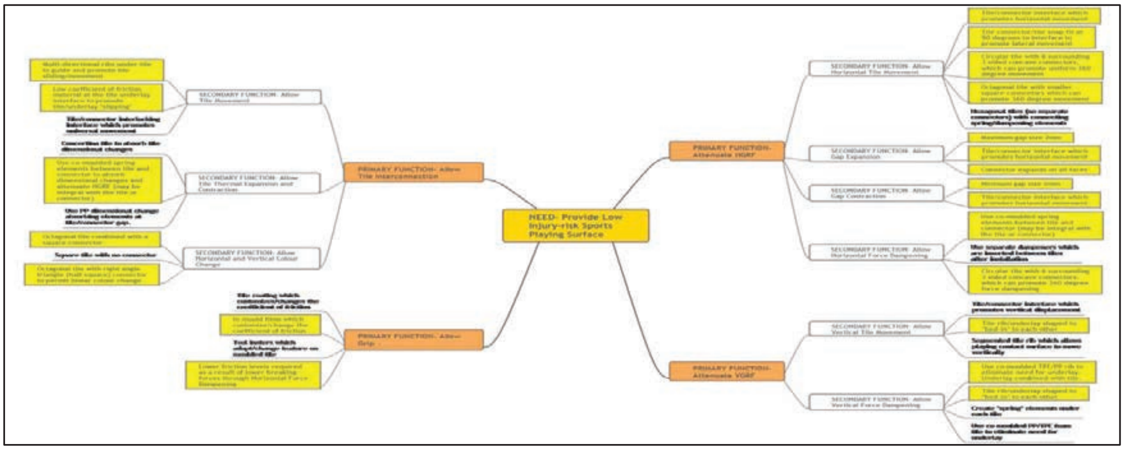

Fig. 5. Solution groupings identified for final development

Figure 6 represents the final iteration of the new sports surface, which features an octagonal tile and square tile connector, as resulting from the new surface development process.

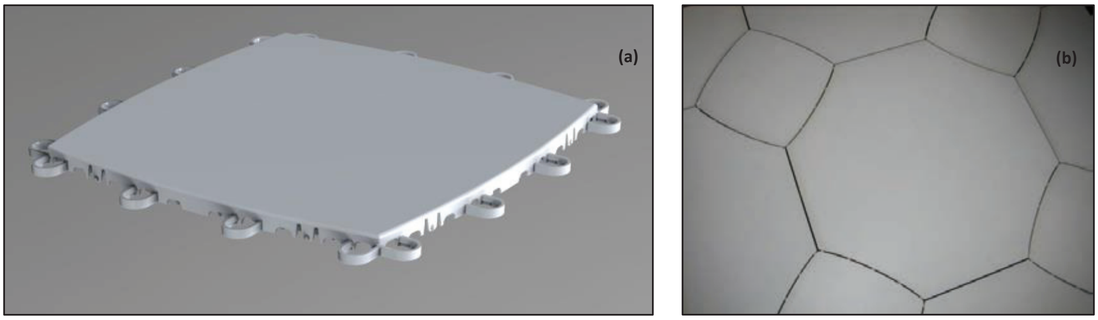

Fig. 6. (a) Proposed square modular connector (b) and octagonal tile and square connector sports surface assembly

Figure 7 (a) shows shows a test simulation onto a homogenous court surface and Figure 7 (b) shows an inclined impact test simulation of the final design iteration, oriented in the 'down-court' direction of the surface (perpendicular into the bottom edge of the new surface test rig). A total of 6 different impact direction confifurations were tested.

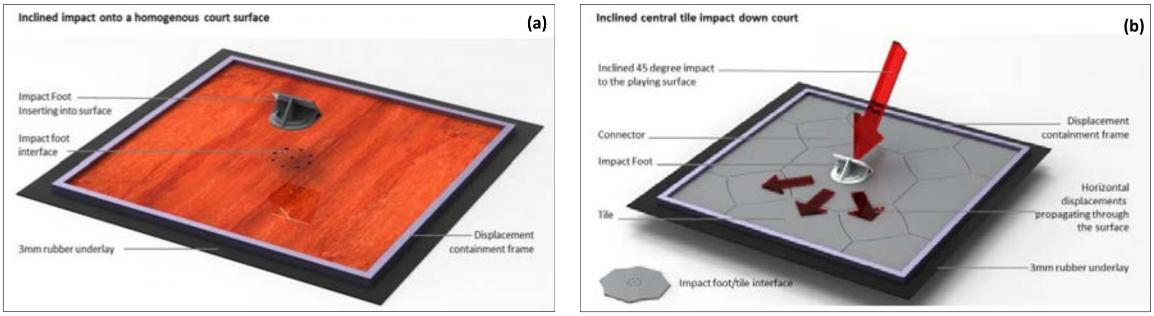

Fig. 7. Surface assembly (a) Homogenous timber court surface test rig (b) Down-court inclined impact validation test

Table 1. Summary of the mean force reduction for horizontal forces generated by an Inclined Impact Test Apparatus in 6 alternative surface test scenarios.

Surface test scenario configuration	Mean Peak HGRF (*N*)	Percentage force reduction in comparison to homogenous surface (*%*)
Homogenous *(timber) sports surface. (Test A configuration).*	2112	NA
New *modular plastic tile sports surface. (Test B configuration).*	560	73.5
New modular plastic tile sports surface. (Test C configuration).	495	76.6
New modular plastic tile sports surface. (Test D configuration).	485	77.0
New modular plastic tile sports surface. (Test E configuration).	562	73.3
New modular plastic tile sports surface. (Test F configuration).	497	76.5
Mean across all new modular plastic tile sports surface scenarios.	520	75.4

In the tests conducted on the new surface, mean peak HGRF recorded across all testing scenarios, represented a potential 75% improvement in force reduction at peak braking force, in comparison to a homogenous timber surface.

4. Conclusion

The creative process followed in this design exercise, has resulted in the development of a novel, commercially improved modular plastic tile sports surface system. This has been realised through the development of an innovative, sustainable, shock attenuating tile and connector geometry, which aims to reduce braking forces on the surface to acceptable levels, and thus reduce the risk of athlete injury.

Floor expansion and the potential for tile buckling are also major issues for most modular plastic tile floor surface manufacturers, as a result of differential rates of linear thermal expansion between the polymer floor and subfloor material. Different coefficients of linear expansion between the floor and subfloor, will normally result in the polymer synthetic surface expanding more than the subfloor when court temperatures increase, generating internal compressive forces in the surface, which may result in the floor buckling or lifting up from the subfloor. The connector element developed through this design process links the octagonal tiles together, with each tile effectively being surrounded by four connectors, creating adjoining 'sprung biased' expansion features around each tile, which close and open as the tiles move under braking forces exerted by the athlete. This feature also provides the ability to locally manage the dimensional changes experienced by the surface as a result of temperature changes.

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