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Development of a sports technology quality framework

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ABSTRACT

Identifying tools and processes to effectively and efficiently evaluate technologies is an area of need for many sport stakeholders. This study aimed to develop a standardised, evidence-based framework to guide the evaluation of sports technologies. In developing the framework, a review of standards, guidelines and research into sports technology was conducted. Following this, 55 experts across the sports industry were presented with a draft framework for feedback. Following a two-round Delphi survey, the final framework consisted of 25 measurable features grouped under five quality pillars. These were 1) Quality Assurance & Measurement (*Accuracy, Repeatability, Reproducibility, Specifications*), 2) Established Benefit *(Construct Validity, Concurrent Validity, Predictive Validity, Functionality)*, 3) Ethics & Security *(Compliance, Privacy, Ownership, Safety, Transparency, Environmental Sustainability)*, 4) User Experience *(Usability, Robustness, Data Representation, Customer Support & Training, Accessibility)* & 5) Data Management *(Data Standardisation, Interoperability, Maintainability, Scalability)*. The framework can be used to help design and refine sports technology in order to optimise quality and maintain industry standards, as well as guide purchasing decisions by organisations. It may also serve to create a common language for organisations, manufacturers, investors, and consumers to improve the efficiency of their decision-making relating to sports technology.

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Introduction

Technology use is accelerating in sport and is showing no signs of abating. The beginning of the 21st century has seen exponential growth in how technology is used to train and monitor athletes, as well as for fan engagement via digital technologies and investable enterprise in areas such as stadium experience, media platforms and content distribution (Beiderbeck et al., 2023; Frevel et al., 2022; Torres-Ronda & Schelling, 2017; Windt et al., 2020). Some common types include wearable sensors, smart equipment, virtual reality devices and vision-based systems. These developments have had a fundamental impact on the way various sports stakeholders conduct their jobs, raising both a number of opportunities and challenges (Figure 1). Notably, staff, leagues, and governing bodies are inundated with more proposals from technology companies in 1 week than they could reasonably review in a year. Athletes, coaches, and parents attempting a simple online search for sports technology are met with an expansive list of options all claiming to be the best on the market. Sports tech start-ups receive considerable mentoring on how to establish a viable business, but in some cases less so on how to determine the actual quality of their product.

Unfortunately, an understanding of how to effectively and efficiently evaluate the quality of sports technologies has lagged well behind market growth. As a result, there is a need for further resources and training for stakeholders to effectively evaluate whether a technology is suitable for their needs. Money and time can often be wasted on technology that is ultimately left to collect dust in corners of sporting facilities, having been quickly found to be ineffective, unusable, too burdensome, or unsafe (Jaswal et al., 2019; Luczak et al., 2020). A further challenge is that the regulatory environment for sport technology is not currently well defined. Like in many industries, the majority of sports technologies are not required to comply with statutory or regulatory requirements. At best, a patchwork of policies exist which are largely contingent on the relevant sport, competition level and geographic region. For example, an Electronic Player Tracking Device (EPTS) worn by an EU-citizen playing in a FIFA (Fédération internationale de football association)-sanctioned match in Belgium is required to:

- Meet the "FIFA Basic" EPTS standard, which evaluates the physical safety of the device during impact, and the accuracy of the position and velocity data provided by the system.
- Meet the regional standard for electrical safety.
- Meet the IFAB (International Football Association Board) standard for data output format.
- Conform to GDPR (General Data Protection Regulation) for data privacy and safety considerations.

However, if the same player uses the device in a Major League Soccer (MLS) game in Chicago, Illinois, there is no requirement

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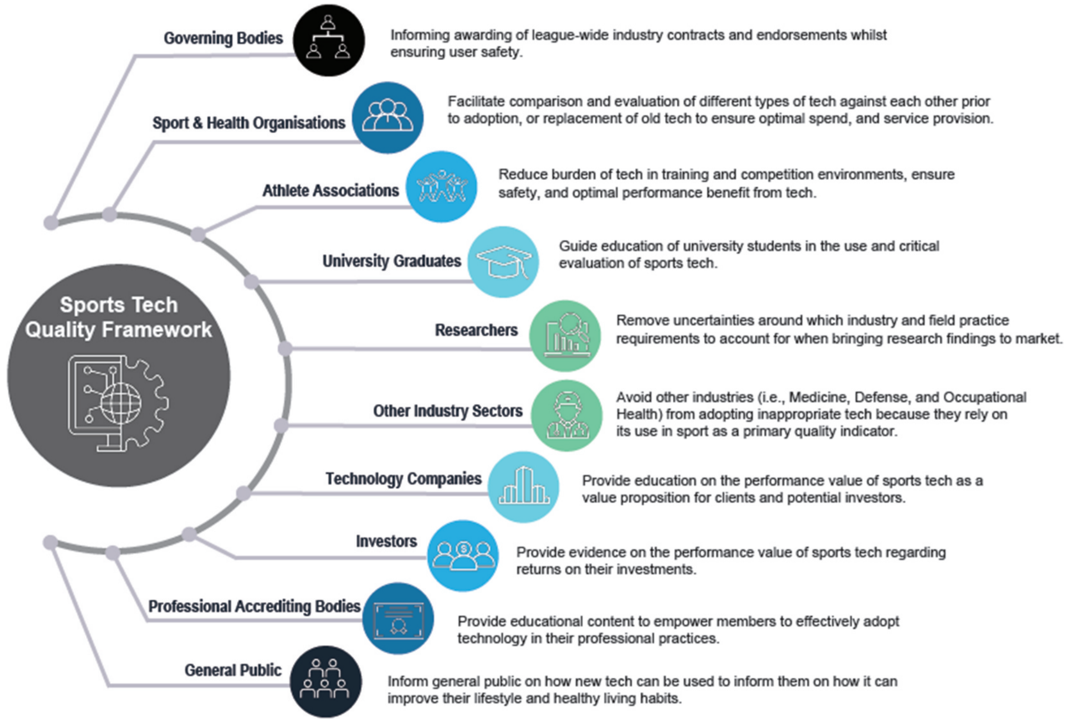

Figure 1. Current challenges for sport technology stakeholders.

for data accuracy, usability, quality, or data output, no data privacy regulation, and no physical safety standard.

Even when policies and regulations do exist, requirements may be present for certain aspects of technology (e.g., physical safety and data privacy) but not others (e.g., accuracy, efficacy or usability of outputs). All of this makes it challenging and expensive for manufacturers to be compliant across sports and localities, because there is no unified standard against which to design and test their product. Given competitive and financial concerns, manufacturers may also be hesitant to disclose technical information on their product, such as how it has been evaluated or how it compares to competitor products. This in turn makes it difficult for the consumer to gain knowledge on which features of a technology have or have not received third-party scrutiny. Combined with the ongoing and rapid updates to algorithms, firmware, and hardware this leaves them often ill-equipped to make an accurate assessment on the quality of a technology, leading to poor decision-making.

Fortunately, progress is being made in addressing some of these challenges. Although definitions typically used to define the quality are intentionally broad (i.e., "the totality of features and characteristics of a product or service that bears on its ability to satisfy given needs" (ISO, n.d.)), researchers have developed important expansions with specific respect to the sporting context. For example, decision-making frameworks have been developed to guide the adoption of technology (Windt et al., 2020) and innovation (Ringuet-Riot et al., 2013) in sporting organisations, along with the proposal of standards for wearable devices (Ash et al., 2020, 2021). Groups such as the Consumer Technology Association are also making important strides in establishing test methods and criteria for specific measures (ASTM, 2022; CTA, 2021). Governing bodies such as the Institution of Mechanical Engineers (IMechE, 2023) have acknowledged the importance of sustainability in technology, whereas IFAB mentioned above, operate the Quality Programme for EPTS (FIFA, 2023). These devices, which utilise various sensors and algorithms to track player position and movement on the pitch, must meet a minimum standard in order to be used in official matches under the auspices of FIFA. The standard evaluates the physical safety of the device to be worn by a player in case of a fall and the accuracy of the position and velocity data provided by the system when used on the pitch. Whilst these combined activities represent steps forward for the industry, a unifying framework consolidating these efforts would help to increase global translation and address many of the previously mentioned challenges.

The aim of this study was to develop a standardised, evidence-based framework to assess the quality of technology, which could be adopted by sport technology stakeholders to develop and improve new and existing products. If successful, this framework could be used to a) help design and refine sports technology in order to optimise quality and maintain industry standard, b) guide purchasing decisions through facilitating comparison of certain technologies that perform the same function with one another, or certain providers of the same tech with one another, and c) create a common tool for organisations, manufacturers, investors, and consumers to improve the efficiency of discussion and decision-making.

Methods

Framework development

In February 2022, a working group of 11 members from four countries (Australia, United States, Belgium & Germany) convened to develop the quality framework. The group formed following joint connection through the Sports Tech Research Network (www.strn.co). Members included researchers, consultants, and practitioners with extensive experience and expertise in sport technology evaluation. This membership ranged from individuals responsible for assessing sports technology quality for governing bodies, start-up company founders, technology researchers and consultants working in quality evaluation. Over the course of 6 months, the group conducted a review of standards, research, and consensus statements on technology assessment in sport as well as adjacent industries, including digital health. Notable examples included the American Society for Testing and Materials (2022) and the Consumer Technology Association (2021). Each group member then independently submitted and presented a list of *features*, defined as "unique measurable aspects relating to the quality of a sport technology", which they considered to be important when evaluating sport technology. These features were compiled into a list by the lead author and presented to all group members in multiple video conferences, with follow-up conversation over email. Commonly occurring features in each independent list were all included in the draft framework, however in some instances similar, yet differently named, responses were grouped together as a single feature (i.e., Feasibility was incorporated under Usability). Such decisions were made based on full written consensus of the group, with the initial draft framework consisting of 25 items. With the intention of ensuring the framework was practically usable, these 25 features were allocated into one of five *pillars*, defined as high level groupings of apparently related features.

Expert panel review

The working group contacted 110 experts in the sport technology field to review and comment on the draft framework. This expert panel was selected to represent the key stakeholder groups: governing bodies and leagues, teams, practitioners, athletes, manufacturers, investors, educators, researchers, and consultants. Members of the working group also presented the draft framework and received feedback at several conferences and meetings where stakeholders would be present, including the Sport Tech Research & Innovation Summit (STRN, Ghent, Belgium, September 2022) and FIFA Research Symposium (Zurich, Switzerland, October 2022).

Formal review of the framework was undertaken using a modified Delphi study design to garner consensus from a group of expert stakeholders (Hasson et al., 2000). This involves an iterative process for anonymously collecting the opinion responses from expert participants (Jones & Hunter, 1995; Woodcock et al., 2020). After each round of consultation, the working group collated the responses and provided feedback to the expert panel with an opportunity to reconsider or update their responses.

Delphi round one

The initial version of the framework was sent to the participants of the expert panel in the form of an online survey and included 25 features arranged under five pillars. Participants accessed the survey via an anonymous survey link which was open for 12 weeks. Definitions and a practical example were provided for each feature. For each pillar and feature participants were asked the following questions: a) Do you agree with the inclusion of this feature in the quality framework?, b) Do you agree with the definition provided?, and c) Do you agree with the example used? A comments box was also included in order for participants to provide written feedback to accompany their response. In the instance that an item (pillar or feature) reached agreement > 75%, consensus was deemed to be reached (Diamond et al., 2014).

Delphi round two

Following round one, consolidated agreement of the framework pillars and features was determined and participant comments addressed. The updated framework, along with responses to participants' comments were sent back to the expert panel for review and revision of their agreement responses. Responses for round two were collected via a second anonymous survey link opened to participants for 7 weeks. At the conclusion of round 2, participant responses were again analysed and the results reported back to the expert panel. Ethical approval to conduct the study was received from the Victoria University Human Research Ethics Committee (HRE22–153).

Results

A total of 48 participants completed round one of the survey, with 29 completing round two of the survey. Participants were from the following geographical regions; Australia ($n = 11$), Belgium ($n = 8$), Canada ($n = 3$), Italy ($n = 1$), Netherlands ($n = 1$), Portugal ($n = 1$), Switzerland ($n = 2$), United Kingdom ($n = 2$), and United States of America ($n = 12$). The organisation type represented by participants completing the survey were: Professional sporting team ($n = 9$), Sports technology company ($n = 9$), Sports technology research and academia ($n = 9$), Elite sport training institution ($n = 8$), Sports governing body ($n = 6$), Athlete/athlete association ($n = 2$), Sports technology investor ($n = 1$). Not all countries and roles are reported as participants were provided the option to keep their demographic data anonymous.

The first round of the survey achieved consensus on all Pillars included in the framework, with Pillar A: Quality Assurance & Measurement and Pillar D: User Experience both reaching 100%. Pillar C: Ethics & Security and Pillar E: Data Management both reached 97% consensus, whereas Pillar B: Value reached 84%. Results relating to the features are shown in Table 1.

Despite consensus being reached on all pillars and features, in considering the written feedback the working group recommended nine changes. These were as follows:

- Changing the name of Pillar B from "Value" to "Established Benefit".
- Changing the name of Feature "Criterion Validity" to "Accuracy".
- Replacing Feature "Reliability" with "Reproducibility".
- Merging Feature "Stability" with "Reproducibility".
- Adjusting "Reproducibility" definition to differentiate from "Repeatability".

Table 1. Round 1 results relating to the survey of the expert panel.

Feature	Consensus: Feature inclusion (%)	Appropriateness of definition (%)	Suitability of example (%)
Criterion validity	100	95	98
Stability	100	91	98
Repeatability	98	98	88
Reliability	100	88	91
Specifications	93	95	93
Construct validity	90	88	86
Concurrent validity	90	95	95
Predictive validity	76	86	86
Functionality	95	88	86
Potential use	76	90	76
Limitations & Delimitations	95	95	90
Compliance	98	93	95
Privacy	95	90	93
Ownership	98	98	95
Safety	98	95	95
Transparency	93	95	100
Usability	98	93	83
Robustness	98	93	88
Interpretability	90	90	90
Customer support & training	95	98	95
Accessibility	95	88	90
Data standardisation	98	88	93
Interoperability	98	100	98
Maintainability	100	100	98
Scalability	95	95	83

- Removing Feature "Potential Use".
- Merging Feature "Limitations & Delimitations" with Feature "Functionality".
- Adding Feature "Environmental Sustainability" to Pillar C
- Changing Feature name "Interpretability" to "Data Representation".

The revised framework was then submitted to the expert panel again for review. This included a report of the Round 1 results (i.e., Table 1) and 60 written responses to panel comments, as well as rationale for the nine recommended changes. In Round 2, consensus was again reached on all aspects of the framework. Similar to Round 1, minor changes to terminology were recommended and accepted by the working group; however no further structural amendments were made. At this point, the framework was developed into a white paper to facilitate interest and uptake amongst sports technology end users and was made available at https://strn.co/special-interest-group. The present manuscript was concurrently developed for submission to authenticate the study methods used to generate consensus and assess its rigour, quality and impact. The submitted framework along with corresponding definitions for each feature are displayed as Figures 2 and 3 respectively.

Discussion

This study represents an incremental, yet important step, towards improving the quality of sports technology. The development of a standardised, evidence-based framework for use across a variety of purposes could provide a consolidated industry approach and enhance efficiency of comparing across different technology options (Figure 4). In this example using mock data, features denoted by a tick have passed a specific standard by the end-user, whilst those displaying a check have not met this standard. Those denoted by an "N/A" are deemed as not applicable for the specific use case. Furthermore, it is intended that the framework will provide a common language for organisations, manufacturers, investors and consumers to communicate unambiguously about the evidence and value of technology. This communication can lead towards creating clear and mutual understanding between all parties, including the end user; thus, supporting effective decision-making in the development and adoption of fit-for-purpose sports technology. As a result of more effective decision-making around technology, it is expected that applied outcomes associated with technology use will improve across sport.

At this initial iteration, the framework is intentionally broad and inclusive. This is inherent in the definition adopted in development of the framework, "to satisfy given needs", which indicates that quality is dependent on context.

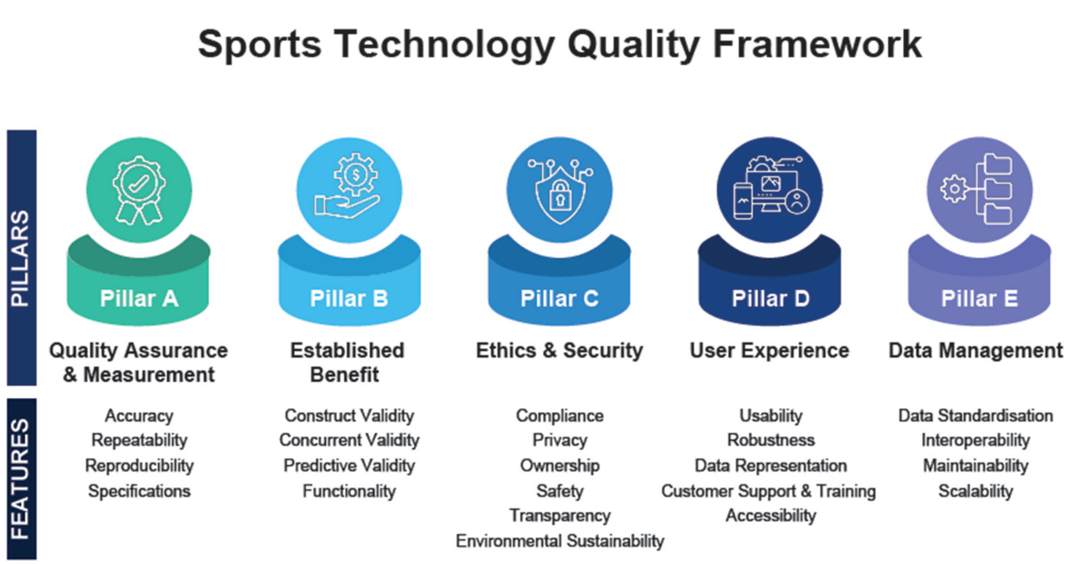

Figure 2. The sports technology quality framework.

	Feature	Definition
A Quality Assurance & Measurement	#1 Accuracy	The extent to which the tech's output relates to a current gold standard for similar measurement (Bellamy, 2015; Robertson et. al., 2014).
	#2 Repeatability	The extent to which the tech's output remains the same under the same test conditions; inluding procedure, users, measuring system, operating conditions and location, and replicated on the same or similar objects over a short period of time (Bartlett & Frost, 2008; Olivieri & Faber 2009).
	#3 Reproducibility	The extent to which the tech's outputs of the same measure remain the same when carried out under changed conditions of measurement. These conditions may include but are not limited to: user; device or device components; location; condition of use; and time. Inter-rater reliability (different users) and stability (extended time-period, such as a multiple months or a season) are considered components of reproducibility (Bartlett & Frost, 2008).
	#4 Specifications	Specifications of the tech such as its capacity, sample rate and dimensions are clearly available to the user (ASTM International, 2022; Joint Task Force Transformation Initiative, 2018).
B Established Benefit	#5 Construct Validity	Ability of tech output to measure a specific area of interest, and/or differentiate between various groups or conditions (Bellamy, 2015).
	#6 Concurrent Validity	Extent to which the tech output relates to a previously validated measure administered at the same time (Cronbach & Meehl, 1955).
	#7 Predictive Validity	Output from the tech has been shown to predict outcome of a future state (Cronbach & Meehl, 1955).
	#8 Functionality	The capability of the tech to provide functions which meet stated and implied needs, when the tech is used under specified conditions. Includes clear stating of intended limitations and delimitations (Azizian et al. 2011).
C Ethics & Security	#9 Compliance	The extent to which the tech is aligned with relevant laws and regulation (Compliance Quarter, 2023).
	#10 Privacy	Extent to which the confidentiality of, and access to, certain information about the user is protected (Barker et al., 2013).
	#11 Ownership	The ability to access, create, modify, package, derive benefit from, sell or remove outputs from the tech, as well as the right to assign these access privileges to others, is clearly defined (Loshin, 2002).
	#12 Safety	Freedom from conditions that can cause death, psychological or physical injury, occupational illness, damage to or loss of equipment or property, or damage to the environment (Stouffer et al., 2015).
	#13 Transparency	Recalls, transparent feature updates, honest and timely reporting are available to users and governing bodies. Security vulnerabilities are reported, identified, assessed, logged, responded to, disclosed, and quickly and effectively resolved, where relevant with two-way feedback (Boyens et al., 2022).
	#14 Environmental Sustainability	The ability of the tech to positively impact, or reduce negative impact to the environment through means of substitution (foster a shift from non-biodegradable and non-renewable to biodegradable and renewable) prevention (reduce or eliminate deterioration and contamination through its use or production) or efficiency (in terms of its demand on energy and resources) (Rubicon, 2023).
D User Experience	#15 Usability	The extent to which a product can be learned and used by intended users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use (Grassi et al., 2017).
	#16 Robustness	The ability of the tech to operate correctly for its intended purpose across a wide range of operational conditions, and display a reasonable life expectancy (Dempsey et al., 2020).
	#17 Data Representation	The interpretability, usefulness and attractiveness of methods used to represent information produced by the tech (New Zealand Curriculum, 2017).
	#18 Customer Service & Training	The extent to which clear use guidelines are provided along with additional training and customer support (Lewis & Mitchell, 1990).
	#19 Accessibility	The extent to which the tech is accessible and equitable to individuals from a range of different groups (Petrie et al., 2015).
E Data Management	#20 Data Standardisation	Data is presented, available in and convertible to a standardised format(s) in line with conventions across a variety of contexts (IAASB, 2021).
	#21 Interoperability	Ability of the tech to physically connect to and logically communicate with other another set of entities at foundational, structural or semantic level's (Barker et al., 2013).
	#22 Maintainability	Extent to which the system's functionality remains stable with minimal disruption to the end-user whilst being upgraded, maintained, or serviced (Heitlager et al., 2007).
	#23 Scalability	The measure of a tech's ability to increase in performance and cost in response to changes in application and system processing demands (Hu et al., 2014).

Figure 3. Feature definitions relating to the sports technology quality framework.

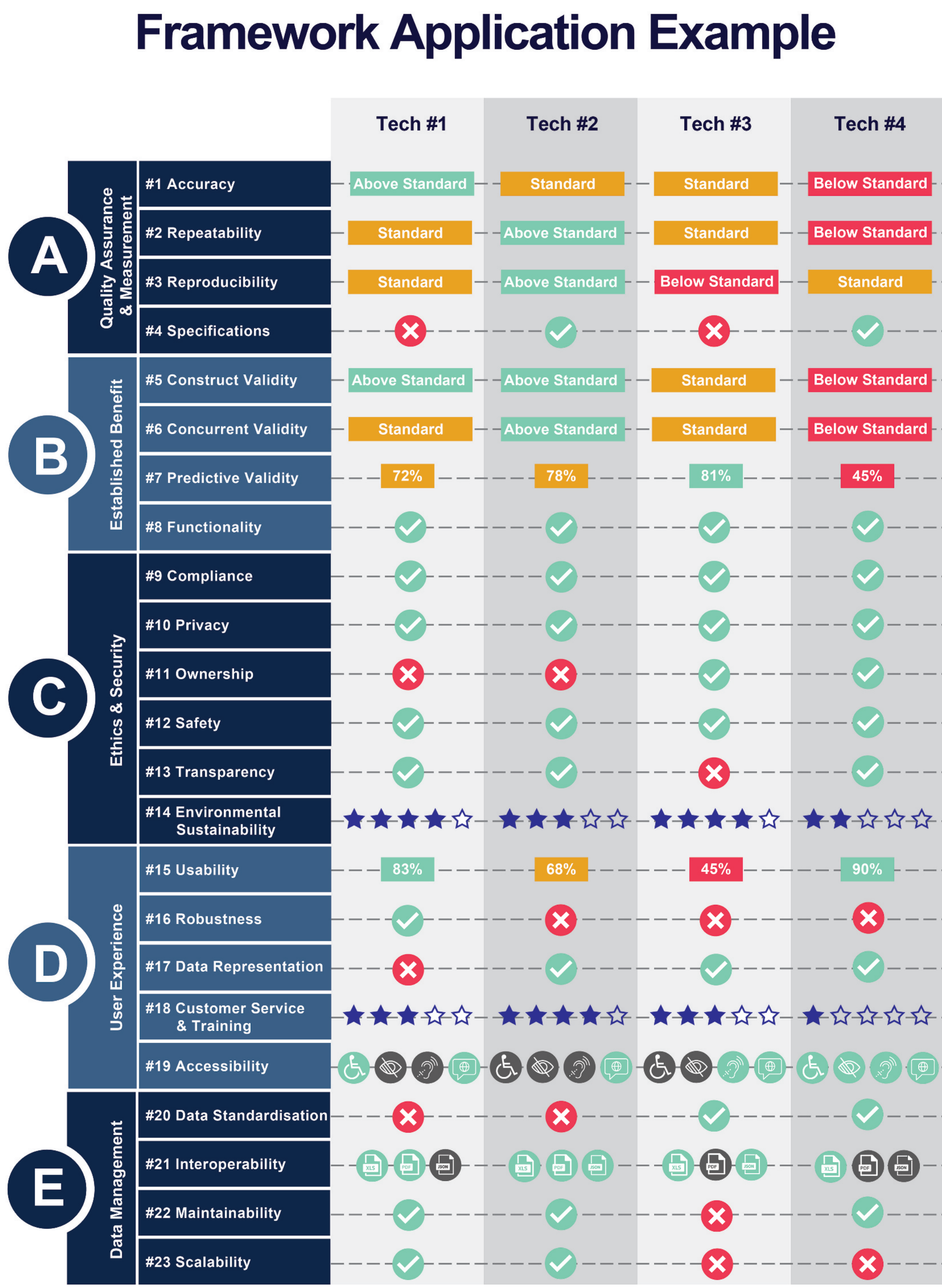

Figure 4. Benchmarking assessment of four different providers of a single technology.

Potential use cases for the framework may include but are not limited to: a start-up company pitching to a sports league, a players union seeking to identify a key technology partner, a team looking to upgrade or purchase new technology, an investment group evaluating a potential target, or a governing body developing policies and regulations. Thus, the decision of a user to adopt certain features of the framework, or weight them differently, may change depending on the use case.

Despite its intended comprehensiveness, it is possible that the framework may also warrant utility when used in a tiered format or when only considering a sub-sample of the pillars or features that are most relevant to the use case. One such model may include a gate-keeper approach, whereby if a technology does not perform sufficiently on a smaller group of features ("Primary Screening"), then it is not progressed for broader assessment ("Secondary Screening") (Figure 5). Such an approach may be particularly effective when many technologies require assessment concurrently, or in scenarios where certain features are weighted more heavily than others.

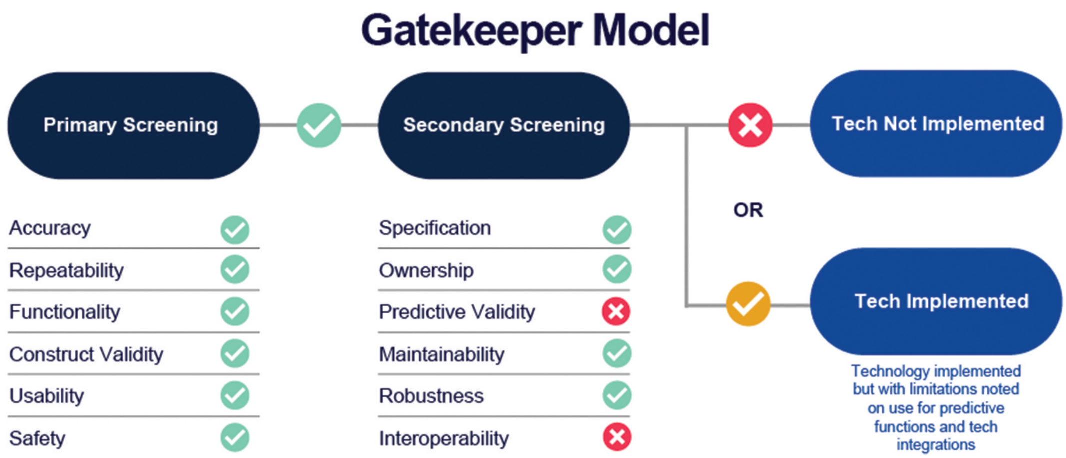

Figure 5. Example of gatekeeper model example, where the user first evaluates a sub-sample of features prior to further screening.

With this inclusivity in mind, the framework stops short of prescribing standards in each of the pillars or features. Standards exist elsewhere for many of the included pillars and features; however, they are typically context-specific and are likely to vary considerably across different technology types, different end-users, and different application environments. For instance, the process by which certain features are assessed for an athlete management system will vary substantially from a heart rate monitor, and certain standards which are deemed acceptable may differ from the elite level to community sport. Appendices A & B show two examples relating how the framework may be used with two different technology types, an EPTS device in professional football and a wrist-worn heart rate monitor in youth track. Consequently, short of developing their own intellectual property in this area, users are recommended to leverage relevant test standards, scientific literature, known applicable requirements and their practical knowledge to guide their decision-making.

It is important to note that the validity of the framework itself is currently unknown. Thus, the extent to which using the framework can improve the financial or decision-making outcomes of organisations has not yet been established. It should also be noted that no specific definition of "sports technology" was provided to participants. Most definitions in the literature of "sports technology" are deliberately broad and inclusive, discussing technology as a man-made means to which human interests and achievements in sport can be achieved (Loland, 2002). The authors also acknowledge that certain participants may have envisioned different types of technologies when providing their responses, however this could also be said to be a strength of the study given its ability to generate heterogeneous responses. It is also worth noting that additional features of relevance may come to prominence in future years and consequently the framework may require review after an initial period. However, at time of publication, the white paper available online at https://strn.co/special-interest-group remains in the identical format to how it is presented in this document.

There are considerable opportunities for future work involving the framework. As mentioned above, case studies and validation of the framework itself are important next steps that are currently in progress by the working group and industry partners. Given the breadth of technology types available to the sports stakeholder, these processes may take on many different forms across the ecosystem. Ultimately, whilst the framework was intended for use with any type of technology, from equipment and clothing through to digital devices, application to a variety of contexts is required to reveal where it ultimately yields greatest benefit. Further expansion on the framework to provide guidance on how to assess each of the features would also likely be of use. Ideally, the framework can also form a part of formal tertiary education and accreditation, areas in which sports technology expertise is currently largely absent. Training materials and advising services may also be considered to improve the technical support provided to start-ups, entrepreneurs, and venture capitalists. It is anticipated that governing bodies will use the framework to inform policy and technology adoption for specific leagues and competitions. Ideally, organisations may also use the framework to help optimise the roles of their staff, by identifying opportunities to outsource or replace, helping to recover much of the time currently lost to technology management.

Conclusion

This study aimed to develop a standardised, evidence-based framework to assess the quality of technology. Based on a combination of existing research, work undertaken in other disciplines and industry feedback, it has myriad potential to immediately advance the sport technology ecosystem. In particular, the framework has the potential to inform the design and refinement of sports technology to optimise quality within industry standards and specified user needs, guide purchasing decisions through more comprehensive and systematic comparison of technologies and/or providers, and promote more effective communications among stakeholders by establishing a common language to discuss sport technology quality. Future work will serve to illustrate the efficacy of the framework across a variety of contexts, along with developing measurable standards for specific use cases.

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Appendix A

Practical Example #1: Athlete Tracking (EPTS) in Professional Football

A — Quality Assurance & Measurement	#1 Accuracy	Level of agreement for outputs such as velocity or position with passive optical marker-based motion capture (i.e., gold standard).
	#2 Repeatability	The ability of a person travelling on an identical path at a known velocity to be tracked by the system on repeat instances.
	#3 Reproducibility	Differences in distance measurements calculated by a tracking device when operated by two different human users.
	#4 Specifications	A tracking device's sampling and reporting rate of 10 HZ, accelerometer sampling rate of 1000 Hz and range of +/-16 g and reporting rate of 100 Hz, gyroscope sampling rate of 100 Hz and range of 2000 deg/s; and 6-hour battery life.
B — Established Benefit	#5 Construct Validity	Data from the tech reveals that midfielders run further distance in a game of professional football comparative to strikers.
	#6 Concurrent Validity	Velocity output from a wearable tracking system showing good agreement with an optical tracking system.
	#7 Predictive Validity	High-speed running metric shown to predict creation of a scoring opportunity in team sport.
	#8 Functionality	Information stating that a global positioning system should not be used with fewer than X satellites.
C — Ethics & Security	#9 Compliance	The system complies with all relevant regulatory bodies from governments to leagues and clubs.
	#10 Privacy	Privacy Statement is provided and readily available, along with a list of those with access to the data.
	#11 Ownership	The tech provider clearly articulates customer vs manufacturer's rights over the data.
	#12 Safety	A wearable tracking device assessed for its potential to cause injury during a fall.
	#13 Transparency	Security breach at a professional match reported to clubs immediately.
	#14 Environmental Sustainability	Development of new hardware that uses available renewable materials and lengthens the life of the product.
D — User Experience	#15 Usability	The tech's score on a scale assessing ease of use for deployment in community football.
	#16 Robustness	The ability of a tracking system to function across various temperature and humidity levels.
	#17 Data Representation	The dashboard outputs provided by the tech manufacturer as rated by an end-user.
	#18 Customer Service & Training	Provision of training and support information available online, along with responsive and adequately trained tech support team during live competition.
	#19 Accessibility	Existence of a language option on the software interface that users can choose from.
E — Data Management	#20 Data Standardisation	Data is downloadable in various formats requested by end user and/or governing body.
	#21 Interoperability	Development of a high-quality and well-documented API.
	#22 Maintainability	The tech manufacturer providing a back-up system to end user during periods of servicing.
	#23 Scalability	Data output by the tech is stored on a cloud service with room for data storage and processing increases.

Figure A1. Framework application example: EPTS in professional football.

Appendix B

Practical Example #2: Wrist-worn heart rate monitor in youth cross-country

A – Quality Assurance & Measurement	#1 Accuracy	Mean absolute error between heart rate reported by the tech and that measured with electrocardiogram (ECG) are within acceptable norms.
	#2 Repeatability	The ability of the tech to measure heart rate with an accuracy similar to gold standard during a running trial at the same speed with the same individual, two days apart.
	#3 Reproducibility	No change in heart rate accuracy is identified when tests are repeated across users with varying skin melanin content, which may affect optical heart rate data.
	#4 Specifications	The tech specifications indicate the watch dimensions, weight, and water resistance, which types of optical sensors are used, heart rate reporting frequency and duration, whether it is reported in activity or resting or continuously, whether automatic or user-triggered, communication protocol, and battery life with and without heart rate tracking engaged.
B – Established Benefit	#5 Construct Validity	The tech has the ability to differentiate the illness status of athletes using its resting heart rate measure.
	#6 Concurrent Validity	The relationship between tech output (e.g., heart-rate based training impulse response/TRIMP) and athlete session rating of perceived exertion (RPE) measured at the same time are established.
	#7 Predictive Validity	The tech detects a decrease in time to recovery of heart rate following standardized running intervals to predict a faster 800 m time.
	#8 Functionality	Manufacturer clearly states that wrist-based heart rate sensor should only be used to measure heart rate variability when at rest, and not during activity.
C – Ethics & Security	#9 Compliance	The tech complies with World Athletics C2.1 6.4.4 if used during international competition.
	#10 Privacy	Personal information stored in the manufacturers cloud is subjected to security and privacy controls in line with applicable best practices.
	#11 Ownership	Users can grant or rescind access to all or parts of data to other stakeholders.
	#12 Safety	The tech is assessed for compatibility of its materials with human skin, potential to cause skin irritation, allergic reaction, burns or other injury or discomfort, when worn as instructed.
	#13 Transparency	Manufacturer notifies users in a timely and clear manner of potential of a specific model of the product to cause skin burns and works with consumers to facilitate a replacement.
	#14 Environmental Sustainability	The tech uses improved battery technology that extends battery longevity and reduces environmental impact when disposed.
D – User Experience	#15 Usability	Clear instructions are provided by the manufacturer for correct device placement and tightness, integration with mobile tablet, and subsequent data download for decision-making purposes and are understandable for both cross country coaches and athletes.
	#16 Robustness	The tech performs equally across a range of workout intensities, temperature, and humidity levels. Bluetooth bandwidth and data storage permit athletes to use without carrying mobile device.
	#17 Data Representation	Tech has the ability to represent and translate heart rate data in an efficient and succinct manner for decision-making by coaching staff.
	#18 Customer Service & Training	Device includes 'Instructions for Use' document and 'Quick Start Guide' to enable efficient operation when used in the field. Customer service contact information is readily available and instructions online.
	#19 Accessibility	Tech provides indication of optimal placements for individuals with compromised upper limb function due to stroke or vascular impairments.
E – Data Management	#20 Data Standardisation	Data can be exported in a non-proprietary file type (e.g., .csv, .json).
	#21 Interoperability	Tech has ability for time-synchronous alignment of data from multiple devices and subsequent integration of said data with the user's athlete monitoring system.
	#22 Maintainability	The ability for tech firmware/software upgrades to occur without data loss or other hindrances that may derail athlete training programs.
	#23 Scalability	The tech systems ability to analyze data from multiple training sessions uploaded from all team members' devices for efficient decision-making.

Figure A2. Framework application example: Wrist-worn heart rate monitor in youth track.