QUALITY ASSESSMENT FRAMEWORK

Bringing the Framework to life

v1.0 December 2024

STRN Sports Tech Research Network

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1. Introduction

The Sports Tech Quality Framework (Figure 1) was released in 2023 to help address the global challenge of evaluating the value, usability and quality of sports technology. Developed in collaboration with experts across the sports industry, the framework consists of 23 measurable features grouped under five quality pillars: Quality Assurance & Measurement, Established Benefit, Ethics & Security, User Experience, and Data Management. In the 12 months since its release, the framework has found diverse applications, gaining traction for a range of strategic and operational purposes, including:

- Benchmarking the quality of different products prior to purchasing, enabling informed decision-making,
- Assisting major sports leagues or governing bodies in selecting tech partners and negotiating contracts, particularly by defining performance milestones for service-level agreements,
- Building technology assessment databases within sports organizations, fostering best-practice technology adoption,
- Facilitating meta-analysis to assess the quality of certain technology types across various contexts,
- Reducing the technology burden faced by organisations, by streamlining the suite of devices and systems used,
- Informing courses and formal education and accreditation programs, enhancing curriculum relevance, and
- Guiding start-ups on maximising product quality to better attract investment.

These many use cases have helped organisations prevent the negative effects experienced due to ineffective, burdensome or unsafe technologies, reduce poor return on investment, as well as help save time and resources of both users and technology developers.

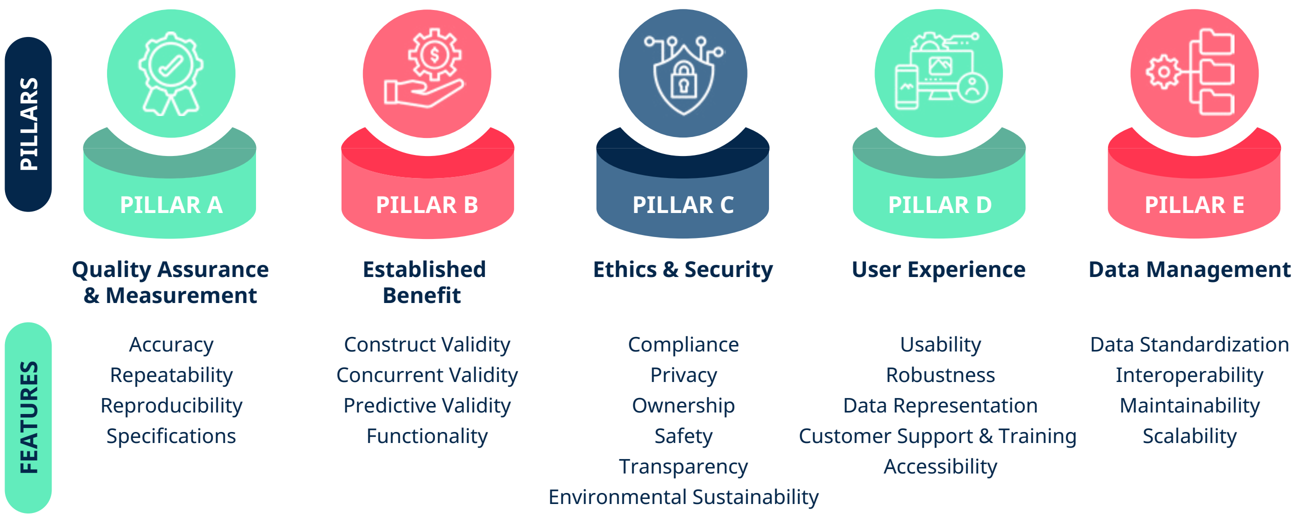


Figure 1. The Sports Technology Quality Framework [1,2]

Building on the foundation established in the initial white paper[1] and peer-reviewed journal article[2] that introduced the framework, this paper is dedicated to offer specific guidance for its practical applications. Additionally, it addresses requests and inquiries from readers and industry stakeholders received in the months following the framework's publication. Through this follow-up, the authors aim to provide actionable insights that enhance the framework's utility in real-world settings and respond to the evolving needs of the community engaging with it. The below sections include:

- Infographics for each of the 23 features, offering
  - Guidelines on how to assess each feature within the framework, enabling consistent evaluation,
  - Examples of current industry standards for each feature which can be readily adopted.
- Operational guidelines for implementing framework and guidelines within sporting organisations
- Case studies showcasing real-world applications of the framework since its release
- Next steps for the framework, including plans for developing additional shared resources, research and ways by which users can get involved.

2. Feature Infographics

This section provides one-page infographics for each of the features included in the Sports Tech Quality Framework, with each infographic addressing the following:

2.1. Feature Assessment

The initial white paper stopped short of providing specific guidance on how to assess each feature. The authors' initial position was, and remains, that the tool or method used to conduct any assessment may differ depending on the context, on the specific use-case of the technology and its intended use. However, in response to overwhelming support and significant feedback requesting additional guidance on available resources, this paper includes easily digestible examples (i.e., infographics). Although not exhaustive, these examples illustrate how each feature in the framework can be evaluated using various readily accessible tools and methods. This added guidance aims to assist users in tailoring their approach while maintaining flexibility in application.

2.2. Example Industry Standards and Guidelines

Each infographic showcases examples of industry standards and guidelines for each of the 23 features, drawing from practice and the literature. Where sport-specific standards are unavailable, adaptable standards from relevant fields are provided. In other cases, where neither exist, guidelines extracted from the literature and/or industry practice have been reported. It is important to note that acceptable standards for each technology will vary depending on the context, intended application, and user. For example, a device's high accuracy might be less critical for recreational athletes than for professionals, and reproducibility may be unnecessary for devices intended (and proven) to be used under the same conditions.

It should be noted that the standards and guidelines illustrated often adopt different types of rating systems, each with its own strengths and weaknesses tailored to specific contexts and purposes. A summary of these rating systems, along with their advantages and limitations, is provided in Table 1 below. Many standards also may represent a blend of the rating styles listed in Table 1. For example, the National Football League (NFL) produces an annual rating of football helmets[3]. The helmets are scored on several performance criteria to produce an overall numerical performance score (continuous rating). Then, they are ranked by best to worst performance (ranking rating). The ranked helmets are displayed in color-coded groupings ranging from dark green (best) to red (worst) based on score (ordinal rating). Finally, a subset below a specific performance threshold are prohibited (hurdle rating).

Table 1. Types of rating systems used to employ sports technology standards.

System	Details	Benefits	Weaknesses	Standards Examples
Hurdle Rating (Minimum Threshold, Pass/Fail)	The tech must meet or exceed a specified criterion to be considered acceptable. This is often seen in a pass/fail model in which a tech must meet a minimum set of criteria to be permitted for use.	Provides a clear binary 'Yes/No' decision and is straightforward to communicate to the end user.	Requires the establishment of an arbitrary line of "good" from "bad". Can lose decision-making nuance, as tech is failed/passed equally regardless of distance from the threshold criterion.	**#16 Robustness** Turf
Ordinal Rating	The tech is assigned to a category based on one or more criteria. The categories are ordinal in that they have relative meaning of increasing acceptability.	Allows for more nuance and information than a binary hurdle rating and remains relatively easy to interpret.	Multiple sets of criteria need to be defined to create the categories, which increases complexity. Nuance as to how close/far a tech is from the dividing line between the two categories is lost.	**#21 Interoperability** Evaluation Models
Continuous Rating	Tech is scored on a given measure that can vary over a continuous range of values. Consequently, the values have inherent meaning (larger percentage error is worse), however the value is treated as informative rather than assigned as a hurdle or category.	There is no loss of information to the user and no need to develop thresholds to assign to categories / hurdles.	Information may be difficult for the user to interpret or action without guidance.	**#1 Accuracy** Aerobic Fitness Wearables
Ranking Rating	The tech is ranked alongside similar products based on performance on a criterion or set of criterion. It also may be further grouped based on its performance relative to the other tech (e.g., above or below average, top 10th percentile).	It does not require the setting of arbitrary thresholds for performance, as all rating is relative, and that it is relatively easy to interpret.	What is acceptable may not be clear (if all tech are poor, does it matter tech is top ranked?) Differences used for ranking may not be meaningful (i.e., if tech has 0.1% higher accuracy, is it a meaningfully higher rank?)	**#12 Safety** Helmets
Blended Rating	Approach encompasses multiple rating elements.	Provides the best elements of all of the previously stated rating systems	May be overly detailed in some instances.	**#10 Privacy** Start ups
Checklist / Guidelines / Domain-Specific Standards	For many features in the framework, a rating scheme may not be suitable. Instead, these features should be evaluated against a checklist or set of best-practice guidelines, with standards often adapted based on the domain and intended user.	User friendly and visually easy to communicate.	Can sometimes lack the granular detail required for an in depth technical understanding of the feature.	**#4 Specifications** Infographic

#1 Accuracy

Definition: The extent to which the tech's output relates to a current gold standard for similar measurement.

How to assess?

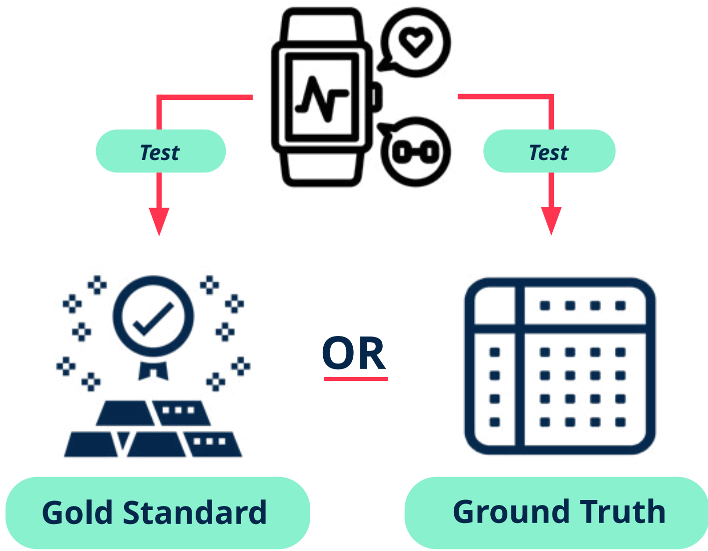
Methods

Inter-System Comparisons between tech and a 'gold standard' or 'ground truth' measure.

Analysis

Many statistical approaches for assessing accuracy between measurements exists such as

- Root Mean Squared Error (RMSE)
- Mean Absolute Error (MAE) / Mean Absolute Percentage Error (MAPE)
- Absolute or Percentage Error Thresholds
- Pearson Correlation Coefficient (r), Lin's Concordance Correlation (CCC)



Example Standards

Heart Rate Monitors

American National Standards Institute (ANSI) / Consumer Technology Association (CTA) [4]

Gold Standard: Clinical ECG

Real-time and longitudinal heart rate monitoring of athletes for performance. Accuracy criteria for beats per minute (bpm)

MAPE: <10%

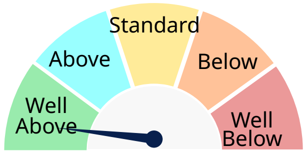
MAE: <10 bpm

Electronic Performance & Tracking Systems (EPTS)

Fédération Internationale de Football Association (FIFA) [5]

Gold Standard: Vicon 3D Motion Capture

Player tracking comparison of Speed (m/s) (RMSE) & Position (m) (MAE), from which tech is categorized (below) against industry standard



Aerobic Fitness Wearables

Peer-reviewed Literature [6]

Gold Standard: Max Oxygen Uptake (VO_2 max)

VO_2max

MAPE = 6.85%, CCC = 0.70

Lactate Threshold

MAPE = 7.52%, CCC = 0.79

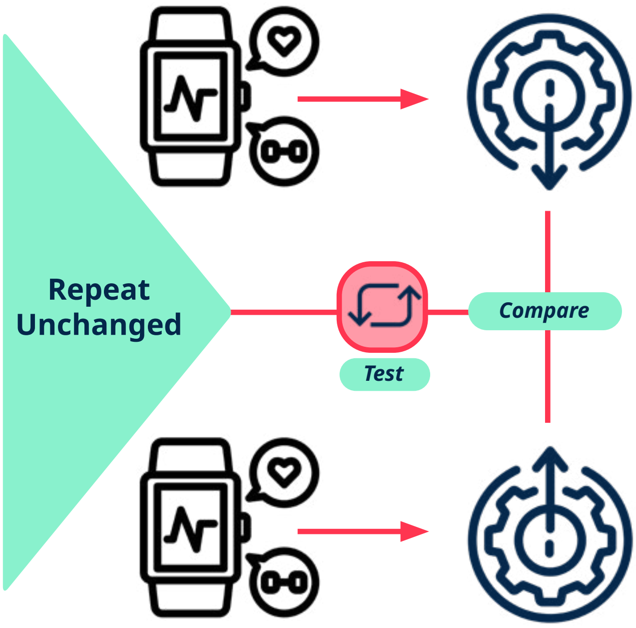
Onset Blood Lactate Accumulation

MAPE = 8.20%, CCC = 0.74

#2 Repeatability

Definition: The extent to which the tech's output remains the same under similar test conditions; including procedure, users, measuring system, operating conditions and location, and replicated on the same or similar objects over a short period of time.

How to assess?



Methods

Assessing the consistency across multiple measurements of the same tech's output under unchanged measurement conditions (environment, procedure, user, test subject, etc.) in which identical outputs would be expected.

Analysis

Many statistical approaches for assessing repeatability between measurements exists such as

- Coefficient of Variation (CV) to measure the variability of repeated tech outputs.
- Bland-Altman Plots to visualize systematic differences across repeated sets of tech outputs.

Example Standards

Heart Rate Devices

Peer-reviewed Literature[7]

Within-device precision

- Report on steady-state activities lasting a minimum of 2 minutes.
- Use average heart rate (HR) over 5-second intervals for each activity (rest & exercise)
- Analyse activities separately to limit within-participant HR biological variation
- Calculate prediction intervals and ICC with 95% CIs

Wearable Tech

Peer-reviewed Literature[8]

Intra-device reliability over unchanged testing conditions

Global Navigation Satellite Systems (GNSS):

1-Hz CV% = 0.4% - 7.7%
5-Hz CV% = 0.3% - 30.0%
10-Hz CV% = 0.4% - 2.2%

Local Positioning Systems (LPS)

CV% = 0.1% - 1.4%

Officiating Tech

International Tennis Federation (ITF)[9]

Tennis competition line-call system installation over 3-7 days. Standard for missed/ incorrect calls over 18 - 120 hours

Replay system
1 x call per 120 hours

Real-time system
0.1% of all calls

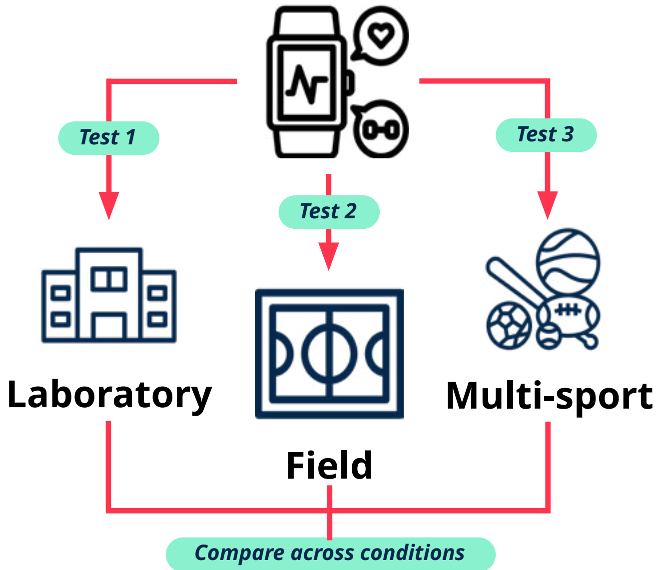
#3 Reproducibility

Definition: 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 multiple months or a season) are considered components of reproducibility.

How to assess?

Methods

Multiple measurements of the same output are taken whilst varying one or more test conditions, such as the user, participant or measurement site. Test condition variations should be relevant to the intended use case.



Analysis

- ***Coefficient of Variation (CV)*** for measuring typical variation across changed conditions
- ***Technical Error of Measurement (TEM)*** for assessing random error
- ***Standard Error of Measurement (SEM)*** for estimating score precision
- ***Intraclass Correlation Coefficient (ICC)*** for evaluating output consistency

Example Standards

Video Tracking

Peer-reviewed Literature[10]

Day vs Day

TEM (%):

Good < 5% | Moderate 5-10% | Poor > 10%

Heart Rate Device

Peer-reviewed Literature[11]

User vs User

Heart Rate Variability (Inter & Intra Researcher)

Children	Young Adults	Middle-Aged
ICC: 0.823-0.989	ICC: 0.822-0.985	ICC: 0.703-0.987
%CV: 3.8-15.9	%CV: 3.3-17.2	%CV: 4.7-21.1

Cycle Ergometers

Peer-reviewed Literature[12]

Day vs Day

Est. Peak Power:	Pedal Velocity:
TEM = 31.9 W	TEM = 5.4 RPM
%CV = 3.5	%CV = 3.8
ICC = 0.986	ICC = 0.924

Resistance Bar Velocity

Peer-reviewed Literature[13]

Equipment vs Equipment

Mean, Mean Propulsive, & Peak Velocity SEM (m/s):

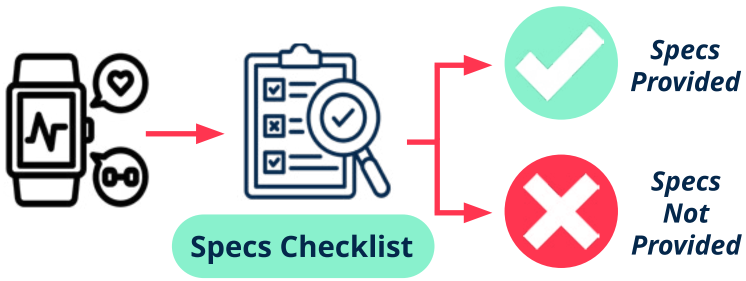
Full Squat	Bench Pull	Bench Press
0.01 - 0.05	0.01 - 0.06	0.01 - 0.08

#4 Specifications

Definition: Specifications of the tech such as its capacity, sample rate and dimensions are clearly available to the user.

How to assess?

Assess the extent to which the manufacturer has provided a list of key technical specifications. A suggested list of such specifications (adapted from ISO/IEC 1977-6:2024[14] & 29136:2012[15]) is provided.



Potential Checklist

Product Identification

- ☐ Brand name & model number
- ☐ Serial number or unique identifier
- ☐ Manufacturer's name & contact information

Technical Specifications

- ☐ Device dimensions & weight
- ☐ Material composition
- ☐ Power (battery and charging)
- ☐ Operating temperature range
- ☐ Measurement units
- ☐ Set-up procedures & calibration intervals

User Interface & Controls

- ☐ Visual of user interface elements
- ☐ Control functions & operation procedures
- ☐ Device modes documented

Data Storage & Connectivity

- ☐ Storage capacity & data retention
- ☐ Data transfer methods
- ☐ Operating systems compatibility

Software & Firmware

- ☐ Software & Firmware versions listed
- ☐ Update information provided

Warranty

- ☐ Warranty period listed
- ☐ Warranty coverage details provided

Example Standards

Tech Labeling

International Organization for Standardization (ISO) / International Electrotechnical Commission (IEC)

ISO 15223-1:2021 [16]**:** Medical Device Labeling	***ISO / IEC 19770-6:2024*** [14]**:** Hardware Labeling Standards	***ISO / IEC 29136:2012*** [15]**:** User Interface Standards

Wearable Tech

International Electrotechnical Commission (IEC)

IEC TC 124 [17] ***& IEC TC 47*** [18]**:**
International Electrotechnical Commission Quality Assessment System for Electronic Components (IECQ)

Material Labeling

American Society for Testing and Materials (ASTM)[19]

Standard procedures for determining a property or constituent of a material, an assembly of materials, or a product

Pillar B | Established Benefit

#5 Construct Validity

Definition: Ability of tech output to measure a specific area of interest, and/or differentiate between various groups or conditions.

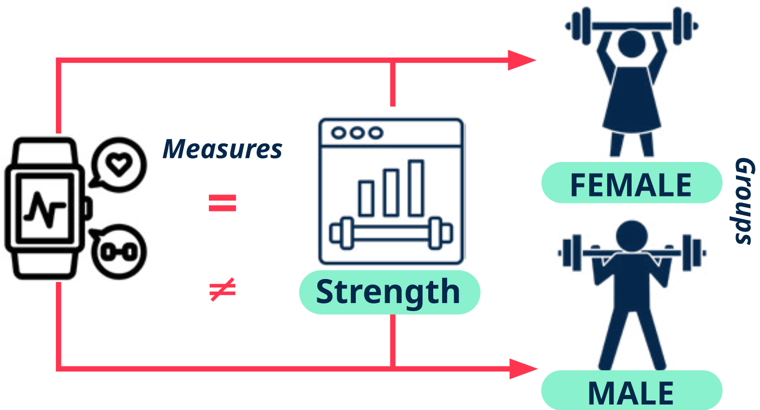
How to assess?

Methods

The user needs to define the output the tech is supposed to measure, then test that output against other established tools or methods that are known to measure the same output (e.g., aerobic fitness, explosive power, tackle count). If the tools or methods come to the same conclusion about the tech's output, it strengthens the claim that the tech is valid for that use.

Analysis

- ***Pearson Correlation Coefficient:*** assesses the strength and direction of the linear relationship between two theoretically related outputs.
- ***Analysis of Variance (ANOVA):*** compares measurements of different groups to see if a it distinguishes between them.



Example Standards

GPS & Accelerometer

Peer-reviewed Literature[20]

Elite & Sub-Elite Rugby
Mean speed, PlayerLoad™ & Metabolic Power

All measures showed construct validity with previous literature.

Virtual Reality

Peer-reviewed Literature[22]

Football-specific VR simulator differentiation of professional, academy, and novice players on passing accuracy, composure, reaction time, and adaptability ANOVA pairwise comparison, Cohens d 0.82-2.73 ($p<0.001$)

Pedometers

Peer-reviewed Literature[21]

Weak inverse relationship (median r = –0.21-0.27) between age and physical activity, body mass index and percentage overweight

Positive weak to moderate relationship (median r = 0.22-0.69) with fitness measures: 6-minute walk test, timed treadmill test & estimated maximum oxygen uptake.

Strength Dynamometers

Peer-reviewed Literature[23,24]

Hand-Held Device

Hip abductor eccentric strength test: average peak force offset of 2.1 (0.6) seconds (range: 0.7–3.7 s; $P \leq .001$).

Mid-Thigh Pull Device

(Rugby League) Isometric peak force (95% LoA: –213.5 ± 342.6 N). Peak force greater in seniors (2261.2 ± 222 N) than youth (1725.1 ± 298.0 N)

Pillar B | Established Benefit

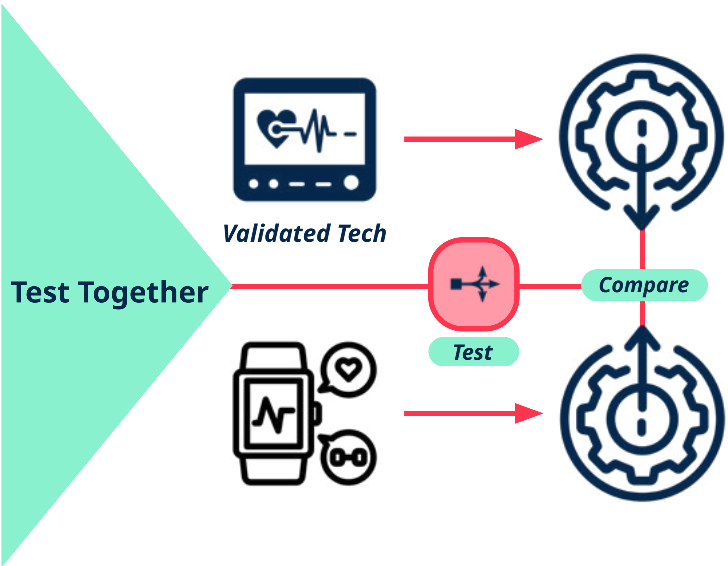
#6 Concurrent Validity

Definition: Extent to which the tech output relates to a previously-validated measure administered at the same time.

How to assess?

Methods

Involves comparing if tech of interest gives similar results to an existing and trusted technology by testing both devices at the same time under the same conditions. Unlike Feature #1, the existing tech may not be the ultimate standard, but is widely accepted and validated for the same measurements of interest.



Analysis

- ***Pearson Correlation Coefficient:*** strength and direction of the linear relationship between two systems.
- ***Root Mean Square Error (RMSE):*** average error between the systems' measurements.
- ***Limits of Agreement (LoA):*** range within which most differences between system measurements are expected to lie.
- ***Intraclass Correlation Coefficient (ICC):*** Measures the consistency between systems.

Example Standards

High-Speed Cameras

Peer-reviewed Literature[25]

High-Speed Camera (HSC) vs Infrared Platform (IR)

Pearson Correlation Coefficient: 99.5% of the shared variance between HSC-Kinovea and IR platform ($p < 0.0001$).

ICC: 0.997, $p < 0.0001$, HSC-Kinovea vs. IR system for flight time and jump height

ICC: 1, $p < 0.0001$, between observers for flight time and jump height

Local Positioning Systems

Peer-reviewed Literature[26]

LPS vs EPTS Tech

RMSE:

LPS vs Laser: 0.24 m

Video vs Laser: 0.73 m

Mean Error:

(Position / Speed / Acceleration)

LPS: 23 ± 67 cm / 0.25 ± 0.06 m/s / 0.68 ± 0.14 m/s^2

Video: 56 ± 16 cm / 0.41 ± 0.08 m/s / 0.67 ± 0.21 m/s^2

GPS: 96 ± 49 cm / 0.28 ± 0.07 m/s / 0.91 ± 0.19 m/s^2

Inertial Measurement Units

Peer-reviewed Literature[27]

IMU's vs 3D Video Motion Capture

RMSE between system joint angles

Knee: 3.3°

Wrist: 3.8°

Elbow: 2.9°

Shoulder: 3.0°

Ankle Plantar/Dorsiflex: 4.2° ± 1.7

Ankle Eversion/Inversion: 4.8° ± 1.2

Ankle Int/Ext Rotation: 10.3° ± 3.0

Pillar B | Established Benefit

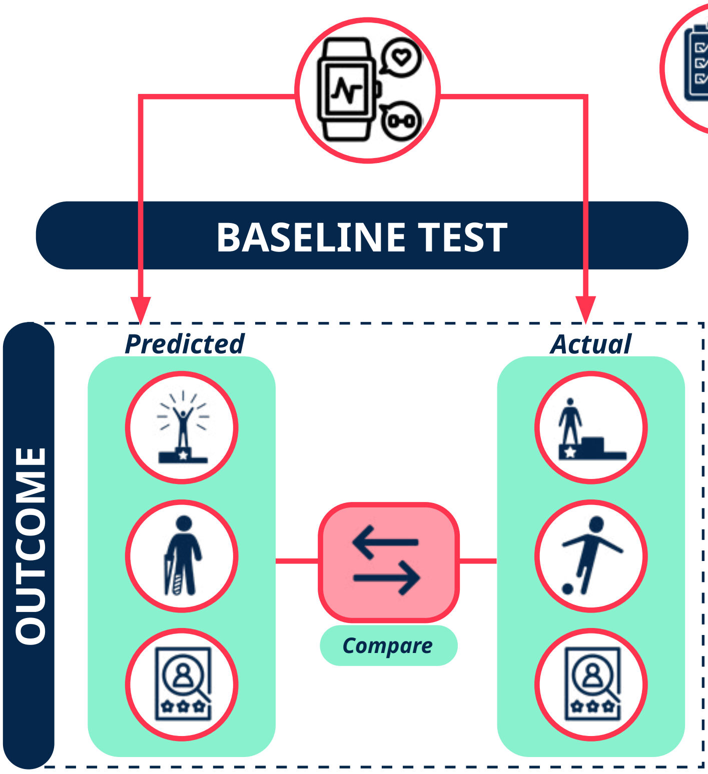
#7 Predictive Validity

Definition: Output from the tech has been shown to predict outcome of a future state.

How to assess?

Methods

To assess the extent a tech measure can predict a given outcome requires users to set a baseline measure followed by a period of tracking outcome measures over time (e.g., sport season, month/year, recovery phase). A comparison of the tech's predictions vs actual outcome measures is then made.



Example Standards

Smart Phone Accelerometer

Peer-reviewed Literature[28]

Balance assessment for injury prediction

Poorer balance = 5.19 greater odds of in-game injury (8.64 greater odds of injury when combined with sport fitness index measure)

DEXA

Peer-reviewed Literature[29]

Childhood Body Mass Index (BMI) predictions on heart health in Adulthood

- BMI at 13 and 27 years: Strongly correlated ($r = 0.38$ at 13 years, $r = 0.55$ at 27 years, $p < 0.0001$).
- BMI increase ≥5.5 kg/m^2: Linked to a significantly greater increase in left ventricular mass index ($p < 0.0001$).

Analysis

- ***Odds Ratio:*** measures the likeliness of a certain outcome is based on the technology's predictions. If the odds ratio is greater than 1, the tech is good at predicting the outcome.
- ***Receiver Operating Characteristic (ROC) and Area Under the Curve (AUC):*** measure how well tech predicts outcomes. A higher AUC means better accuracy, while 0.5 is no better than random guessing.

Analysis Methods

Peer-reviewed Literature[30]

Receiver operating characteristic (ROC) & Area Under the Curve (AUC) ranges

Predictive Validity Description	ROC Value (AUC)
Fail	0.5-0.6
Poor	0.6-0.7
Fair	0.7-0.8
Acceptable / Good	0.8-0.9
Excellent	0.9-0.99
Perfect	1.0

#8 Functionality

Definition: 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.

How to assess?

The checklist below provides a subset of potential questions that users can use to evaluate a technology's functionality for its intended users (e.g., novices, experts, individuals with disabilities), use cases (e.g., sports, healthcare), or specific conditions (e.g., indoor vs. outdoor settings, aquatic environments). These questions should be customised to align with the technology's specific use case.

User Environment

- ☐ Can it work in the intended environment? ***Example:*** *Temperature range, humidity range, water resistance/ waterproofness, lighting, indoors vs. outdoors, playing surface, vibrations, etc*

Physical & Technical

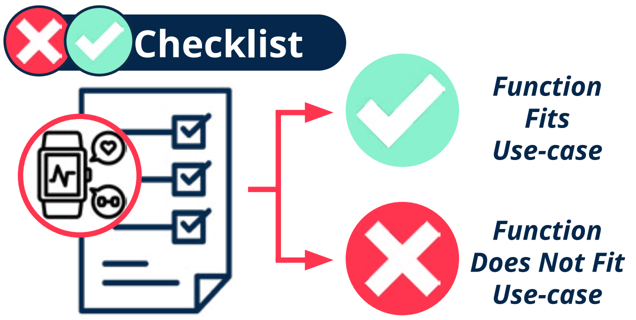
- ☐ Are its physical dimensions, shape, and weight suitable?
- ☐ Are the sensors used for measurement appropriate?
- ☐ Is the measurement range and sensitivity (resolution) sufficient?
- ☐ Does it have a sufficient sampling rate to capture meaningful changes in the data of interest?
- ☐ Does it have sufficient on-board data storage capacity?
- ☐ Is the battery life sufficiently long?
- ☐ Are the duration to re-charge and method of recharging feasible?

Connectivity & Compatibility

- ☐ Is the data connection method (e.g., Bluetooth) and connectivity range appropriate?
- ☐ Is the software compatible with the intended computer hardware?

User Suitability

- ☐ Is the tech indicated (or contraindicated) for the intended user or use case?



Example Standards

Photo Finish Systems

World Athletics[31]

International Competition	***Other Competitions:***
1000 image/second	100 images/second

Synchronization with a uniform time scale (0.01 sec)

Heart Rate Variability Devices

Task Force of the European Society of Cardiology the North American Society of Pacing Electrophysiology[32]

- Minimum sampling rate of 250–500 Hz for accurate HRV analysis
- Sampling rate as low as 100 Hz may be satisfactory with proper interpolation methods

Sleep Monitoring Devices

CTA[33]

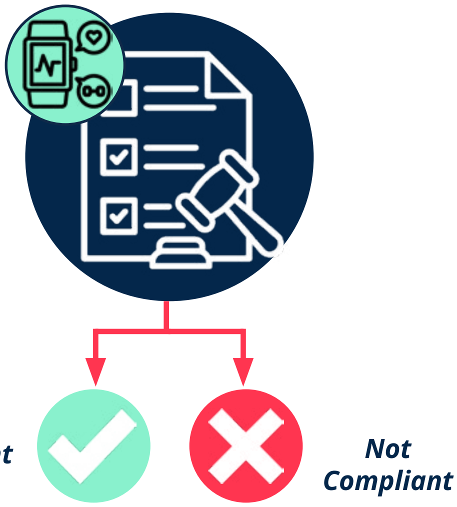
Standard defines terms and characteristics used to describe sleep, including device functionality necessary to measure those characteristics

#9 Compliance

Definition: The extent to which the tech is aligned with relevant laws and regulation.

How to assess?

Checklist to establish whether the tech meets the relevant laws and regulations in the region(s) in which it is being used.



Checklist

- ☐ Is the technology supplier registered as a business, company or corporation as required by the relevant jurisdiction?
- ☐ Is the technology supplier compliant with relevant jurisdiction legislation concerning business operations?

  (E.g., consumer law, employment law, liability and insurance)
- ☐ Is the technology owned, licensed or otherwise permitted to be sold or hired?
- ☐ Is the technology compliant with product safety laws or regulations?
- ☐ Is the tech compliant with regulations of the applicable sport governing body?
- ☐ Is the tech compliant with applicable data protection laws?

Example Standards

Product Labels

California Office of Environmental Health Hazard Assessment (OEHHA)[34]

Proposition 65

Product sold in California (USA) are required to provide potential consumers with "reasonable warning" if a product contains a detectable amount of any substance listed on Proposition 65 list of chemicals that cause cancer and/or reproductive harm

Electronic Devices

European Commission[35]

CE Mark

All electronic products intended for sale in the European Economic Area are required to carry CE marking indicating that it complies with all relevant EU directives for electronics and electrical equipment.

Sports Compliance Audit

Skillcast[36]

Sport's Key Compliance Risks: Compliance audit checklist for three distinct pillars of sporting compliance

1. The sports club or association
2. Under-18's in sports
3. Sports spectators

#10 Privacy

Definition: Extent to which the confidentiality of, and access to, certain information about the user is protected.

How to assess?

Privacy evaluation process (adapted from the GDPR[37]) involves mapping the data flow and stakeholder's access to private data, assessing privacy risks (including a provider's role in privacy risk management), and verifying a provider's legal compliance and certifications. A user may also choose to conduct a privacy impact assessment to evaluate the impact and likelihood of privacy breaches, assign risk levels, and plan for risk mitigation.

Checklist

Data Scope & Mapping

- [ ] Is the technology data flow clear? *(e.g., collection, storage, processing, sharing)*
- [ ] Are key stakeholders clearly identified? *(e.g., developers, users, third parties)*

Check Legal Compliance

- [ ] Does the tech provider adhere to applicable privacy regulations? *(e.g., GDPR, CCPA).*
- [ ] Are there avenues to verify compliance with user rights? *(e.g., access, modification, deletion)*

Risk Evaluation

- Assess the impact of identified privacy risks to users.
- Determine the likelihood of each risk occurring.
- Assign risk levels (low, medium, high).

Identify & Mitigate Privacy Risks

- [ ] Does the provider disclose potential risks of data breaches?
- [ ] Is the provider transparent in reporting previous data breaches?
- [ ] Does the system protect against unauthorized access (e.g., multi-authentication)?
- [ ] What level of ownership (Feature #11) and control does the user have over their data? *(e.g., consent, access, deletion)*
- [ ] Are users able to implement technical privacy controls? *(e.g., encryption, access management)*
- [ ] Are organisational controls regarding tech usage and data able to be implemented? *(e.g., policies, training, incident response)*

Example Standards

Data Protection

Council of the European Union (EU)[37]

General Data Protection Regulation

Mandate that enforces transparency in data processing, requires consent, grants individuals rights over their data, and imposes strict protection measures with penalties for non-compliance.

Start-Ups

Cyber Security Certification / Australia (CSCAU) / ISO / IEC[38,39]

SMB1001:2025 Dynamic Standard [38]

Multi-tiered cyber security certification for small-medium start-ups as they mature to ***ISO/IEC 27001 standard*** [39]

	Bronze		Platinum
	Silver		Diamond
	Gold		ISO/IEC 27001

Wearables

Institute of Electrical and Electronics Engineers (IEEE)[40]

IEEE: 360 - 2022

Standard specifications for basic security of wearable electronic devices in areas such as

Health, Fitness, & Infotainment

#11 Ownership

Definition: 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.

How to assess?

Ownership can be evaluated using the checklist adapted from European Union (EU) general data protection regulation (GDPR[37]). This information is usually disclosed in a provider's "Terms & Conditions" and "Privacy" statements

Checklist

1. Data Access Control
2. Data Creation Rights
3. Data Modification Permissions
4. Access Privileges
5. Data Packaging and Portability
6. Benefiting from Data
7. Third-Party Data Sharing/Transfer
8. Right to Erasure
9. Data Retention Policy
10. User Consent & Rights

Example Standards

Data Rights

EU[37]

The GDPR defines:

- Individuals' fundamental rights in the digital age
- The obligations of those processing data
- Methods for ensuring compliance
- Sanctions for those in breach of the rules

Data Sharing/Exchange

IEEE[41]

IEEE: 1752.1

Standard for open mobile health data ensures consistent representation of metadata, sleep, and physical activity measures, enabling meaningful data sharing and exchange.

Athlete Governance

Australian Institute of Sport (AIS)[42]

Best Practice Principles

Document providing advice to the Australian national high performance sport system on delivering best practice governance of technology and athlete information.

#12 Safety

Definition: 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.

How to assess?

This checklist may be used to assess the safety, testing, and suitability of tech, ensuring it meets standards, aligns with intended use, and provides necessary manufacturer support. It can allow informed decisions to be made about potential risks and benefits of tech

Safety Checklist

Regulatory Compliance & Certification

- ☐ Does the tech meet relevant safety standards (*e.g., electrical, battery, biocompatibility*)?
- ☐ Is it certified by a recognized lab (e.g., Intertek, Underwriters Laboratory)?
- ☐ Has it been safety tested, and what were the results?

Risk & Hazard Assessment

- ☐ Has a hazard assessment been conducted?
- ☐ Does the tech's risk exceed acceptable levels for the sport?
- ☐ How do the benefits compare to the risks?

Manufacturer Info & Support

- ☐ Is the supplier reputable?
- ☐ Does the manufacturer offer product registration for safety updates/ recalls?
- ☐ Is there a contact for safety concerns?

Usage & Instructions

- ☐ Are instructions clear and adequate?
- ☐ Does the use case align with the manufacturer's intent?
- ☐ What safety information is provided, and is it of good quality?

Product History & Issues

- ☐ Are there known safety issues or recalls for this product/category?
- ☐ Has it been used before, and were there any safety concerns?

Example Standards

Helmets

National Football League (NFL)[3]

2024 Helmet Laboratory Testing Performance

Helmets ranked by laboratory-tested ability to reduce head impact severity

1	Better Lab Performance
2	Not Recommended
3	Newly Prohibited

Battery Safety

U.S. Division of Homeland Security and Emergency Services[43]

Lithium-Ion Battery: A Consumer Safety Guide

Consumer guide on correct battery type and usage, warnings on common dangers associated with battery misuse, provision of safety guidelines for charging rechargeable batteries

Risk Assessment

Digital Medicine Society (DiMe)[44]

V3 Use related risk assessment guide

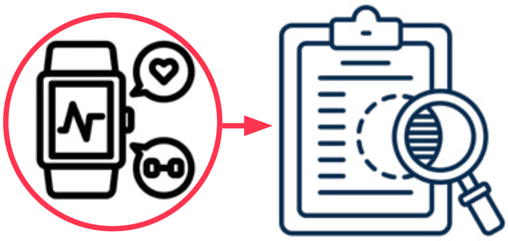
User guide for tech developers, users and researchers on how to develop, evaluate, and deploy safe, effective, and trustworthy digital measurement products

#13 Transparency

Definition: Recalls, transparent feature updates, honest and timely reporting 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.

How to assess?

Users may find relevant transparency information on a provider's "support" page which can then be compared to the suggested checklist adapted from Solana-González et al[45]. The checklist allows users to evaluate a tech company's transparency of information transmission.



Example Standards

Data Security & Communication

National Institute of Standards & Technology (NIST)[46,47]

SP 1800-28 [46]:

Identifying and handling data breaches. Transparency for data breaches, how to convey to users.

CSF 2.0 [47]:

The NIST Cybersecurity Framework (CSF) 2.0

Mobile Health

CTA[48]

CTA 2073:

Guiding principles of practice and transparency for mobile health solutions

Risk Management

IEC[49]

IEC: 80001-2-8:

Security related capabilities related to user needs. Application of risk management for IT networks incorporating medical devices.

Potential Checklist

Service Delivery & Support

- ☐ Is there an easily accessible platform for user feedback and issue resolution?
- ☐ What is the provider's response time to user-reported issues?
- ☐ Are claims processed promptly?

Security & Continuity Management

- ☐ Are security and privacy breaches promptly reported to affected users?

Operational Resources Management

- ☐ Are recalls publicly declared and resolved in a timely manner?
- ☐ Is a recall history publicly available?
- ☐ Are timelines for firmware and software versions disclosed and accessible?

Performance Management

- ☐ Are system updates clearly communicated to end-users?
- ☐ Are critical system changes or issues publicly reported?

Internal Control Monitoring

- ☐ Does the company actively monitor and control changes and issues with their technology?

Regulatory Adherence & Governance

- ☐ Are system or hardware changes compliant with Features #9-12?

#14 Environmental Sustainability

Definition: 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).

How to assess?

The adapted checklist, based on the Green Built Alliance's[50] guidelines, enables users to verify a tech manufacturer's environmental sustainability claims and certifications against relevant green product criteria.

Checklist

Material Assessment

- ☐ Are materials sustainably sourced and durable?
- ☐ Are toxic chemicals present?

Energy Efficiency & Carbon Footprint

- ☐ Is the tech energy-efficient and produced with renewable energy?
- ☐ Are carbon offset programs available?

Regulatory Compliance & Certification

- ☐ Does the tech comply with regulations and have environmental certifications?

Waste Management

- ☐ Can waste be minimized and recycled?
- ☐ Are take-back or recycling programs offered?

Example Standards

Tech Certifications

Global Electronics Council / ISO[51,52]

Electronic Product Environmental Assessment Tool (EPEAT)[51]:

Global eco-label for electronics & tech

ISO 14001[52]:

Environmental management systems requirements

Energy Star Rating

Environmental Protection Agency (EPA)[53]

Certification for energy efficiency and environmentally sustainable products and practices

★★★☆☆

Sustainability Reporting

Global Reporting Initiative[54]

Standards to for reporting sustainability impact on environment for targeted users (e.g. investors & consumers)

#15 Usability

Definition: 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.

How to assess?

This list provides a road map to identify applicable tools, approaches, or frameworks that can be tailored to a tech product to assess usability using quantitative and qualitative analyses.

Scope and Objectives

- Define the technology's purpose, features, intended outcomes, and benefits (e.g., user satisfaction, safety, effectiveness).
- Sample frameworks/metrics: usability score, time-on-task, error rate.

Intended User Base

- Identify user demographics, needs, and environments (e.g., age, physical challenges, usage context).
- Sample approaches/frameworks: Focus Groups, User Interviews, Jobs-to-be-Done (JTBD).

Use Cases & Functional Requirements

- Define use cases and requirements.
- Sample approaches/frameworks: Participatory Design, User Journey Mapping, Competitive Analysis

Domain & Context-Specific Constraints

- Address constraints using standards.
- Sample frameworks/standards: Heuristic Evaluations, ISO 9241-210:2019.

User Testing

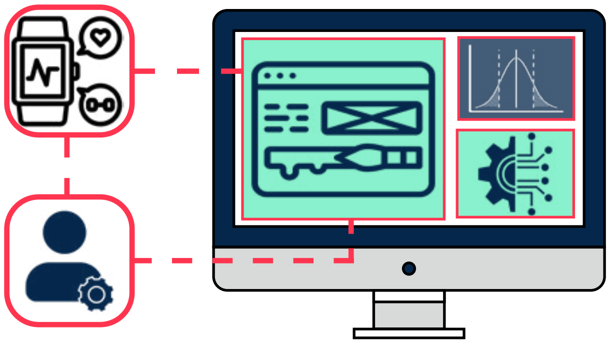
- Conduct iterative usability tests with real users.
- Sample frameworks/ tools: PSSUQ, Kano Model, Multi-generation Product Testing, Moderated Testing.

Usability Reporting

- Document test results and evaluations in usability reports by utilising applicable risk analysis frameworks and mitigation strategies.

Post-Launch Monitoring & Continuous Improvement

- Collect real-world usage data to drive updates.
- Sample approaches: Competitive Reviews, Customer Surveys, Data Analytics.



Example Standards

Tech Software & Products

Peer-reviewed Literature[55]

PSSUQ Norms (Mean, 99% CI)

- Overall Rating (Q1-16): 2.82 (2.62 to 3.02)
- System Usefulness (Q1-6): 2.80 (2.57–3.02)
- Information Quality (Q7-12): 3.02 (2.79–3.24)
- Interface Quality (Q13-16): 2.49 (2.28–2.71)

Digital Health Technology

DiMe[56]

V3+ Essential Usability Questions

User guide for tech developers, users and researchers on how to conduct a use-related risk analysis of digital health tech devices and platforms

Human-Machine Interactions

National Aeronautics and Space Administration (NASA)[57]

NASA Task Load Index (TLX) assesses subjective workload from users in six areas

- Mental Deman
- Physical Demand
- Temporal Demand
- Performance
- Effort
- Frustration

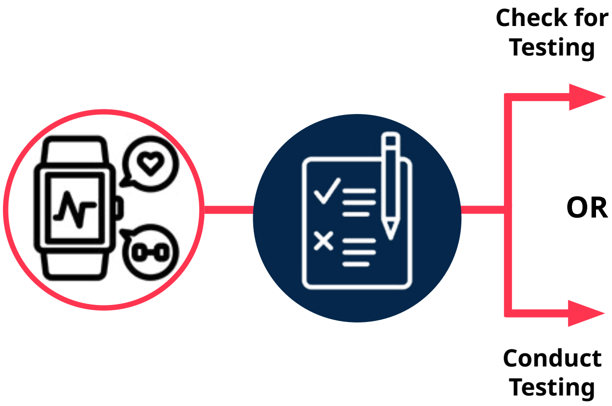
Pillar D | User Experience

#16 Robustness

Definition: 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.

How to assess?

To assess a device's robustness, the end user should verify whether the provider has conducted relevant robustness tests under the conditions outlined here, aligned with the intended use of the technology. Providers can also use this list as a guide to perform robustness testing on their products, ensuring consistent performance across different usage durations and manufacturing lots.



Have these tests been conducted?

- FATIGUE TESTING
- WEAR & TEAR TESTING
- ACCELERATED LIFE TESTING
- ENVIRONMENTAL TESTING (Temperature & Humidity Extremes)
- LOAD TESTING
- DROP & IMPACT TESTING
- THERMAL CYCLING
- VIBRATION TESTING

Example Standards

Wearable Textiles

British Standards Institution[58]

Test method for assessing washing durability of e-textile products (and other durability measures). Ability of e-textiles to be washed and maintain their usability

Athletic Equipment

Peer-reviewed Literature[59]

Influence of injection molding manufacturing process (table) on athletic equipment quality and durability

1	Injection Speed
2	Pressure
3	Temperature
4	Cooling Time

Turf

FIFA[60]

Turf Standard 03.21: Procedure for Artificial Weathering

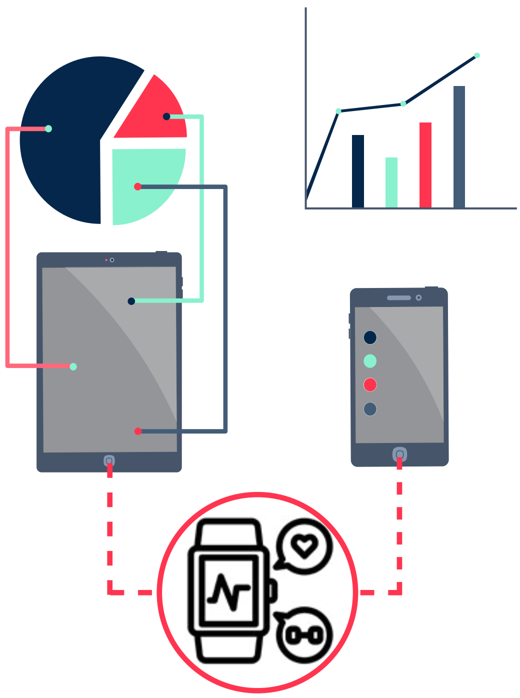
Test method for artificial weathering of football turf involves exposing yarns and infill materials to UVA lamps to simulate UV weathering effects.

#17 Data Representation

Definition: The interpretability, usefulness and attractiveness of methods used to represent information produced by the tech.

How to assess?

A sample method for assessing a tech's data representation is the Data Visualization Effectiveness Profile[61], which evaluates seven key criteria falling into two general categories: i) informative (i.e., produces understanding) and ii) emotive (i.e., produces a useful emotional response).



Informative

- Usefulness
- Completeness
- Perceptibility
- Truthfulness
- Intuitiveness

Emotive

- Aesthetics
- Engagement

Example Standards

Health Data Reporting

CTA / ANSI[62]

CTA/ANSI 2093

Best practices document for reporting format for Timestamps, Sourcing: Recording Data with Attribution, Physical Location, Sensor Location, Battery Status, and Origin to be used for health fitness, and wellness data.

Mobile Health Meta-data

IEEE[41]

IEEE: 1752.1

Standard for open mobile health data representation of sleep and physical activity measures meta-data to allow meaningful language for data sharing and exchange

Data Visualization

Perceptual Edge - Visual Business Intelligence[61]

Data Visualization Effectiveness Profile

Seven key criteria for evaluating data visualization effectiveness, including ranking scales.

Category	Criteria	Rating Scale
Informative	Usefulness	Useless - Very Useful
	Completeness	No Relevant Data - All Relevant Data
	Perceptibility	Unclear & Difficult - Clear & Easy
	Truthfulness	Inaccurate/Invalid - Accurate/Valid
	Intuitiveness	Difficult to Understand - Easy to Understand
Emotive	Aesthetics	Ugly - Beautiful
	Engagement	Distract from Data - Draws one into Data

#18 Customer Support & Training

Definition: The extent to which clear use guidelines are provided along with additional training and customer support.

How to assess?

This checklist, adapted from Meuter et al.[63], can help evaluate a provider's customer service and training quality, including self-service options, employee-led support, and warranty and repair services.

Customer Self-Service & Training

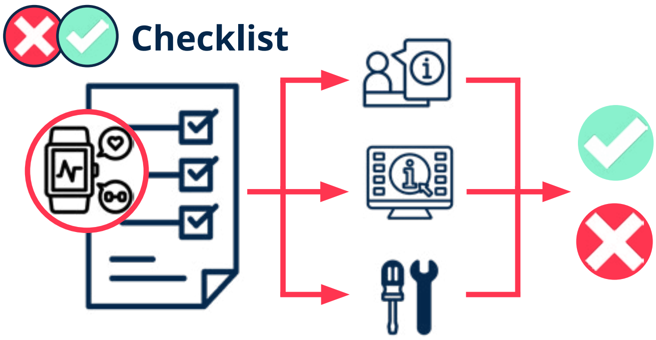
- ☐ Is there an FAQ section available online to answer common customer questions?
- ☐ Are the manuals easily accessible online?
- ☐ Are they updated in line with updates to the technology?
- ☐ Are customers notified of updates to the technology?
- ☐ Are there instruction videos and other customer support content readily available?
- ☐ How helpful is the content?

Interpersonal Customer Service & Training

- ☐ Is there a customer support phone or email?
- ☐ How responsive is the customer support contact to requests?
- ☐ Is there an ability to escalate urgent requests?
- ☐ Does the manufacturer provide training when a system is purchased?
- ☐ How extensive is that training?
- ☐ Is the user required to pay for an annual service contract?
- ☐ What does that contract provide to the customer?

Warranty and Repairs

- ☐ Are warranty period and coverage details clearly provided and appropriate?
- ☐ What is the return and repair policy?
- ☐ What is the typical turnaround time on repairs?



Example Standards

Self-Service Technologies

Peer-Reviewed Literature[63]

Analysis of > 800 customer interactions with self-service technologies (SSTs) to identify customer satisfaction drivers and SST impact on customer behavior

Service Encounters

Peer-Reviewed Literature[64]

5 Determinants of Service Quality

1. Tangibles, 2. Reliability, 3. Responsiveness, 4. Assurance, 5. Empathy

Wearables

Advancement of Medical Instrumentation (AAMI)[65]

AAMI - TIR49:

Training and instructional material for medical devices used in non-clinical environments

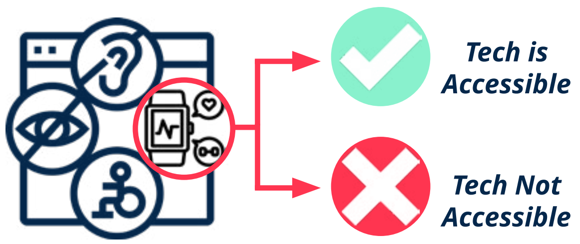
#19 Accessibility

Definition: The extent to which the tech is accessible and equitable to individuals from a range of different groups.

How to assess?

One method if conducting an Accessibility guideline compliance check is to compare the tech features against established guidelines like WCAG, or WAI-ARIA. The following checklist has been adapted from the WCAG 2.0 guidelines[66] for the purpose of screening a tech's accessibility.

Checklist



Perceivable

- ☐ Does tech provide text alternatives (e.g., large print, Braille, speech, symbols or simpler language)?
- ☐ Does tech provide captions or other alternatives for multimedia?
- ☐ Does tech present content in different ways without losing information or structure? (e.g., simpler layout, sensory characteristics such as shape, color, size, or sound)?
- ☐ Does tech make it easier for users to see and hear content (e.g., text-to-speech)?

Operable

- ☐ Does tech make all functionality available from a keyboard?
- ☐ Does tech provide users enough time to read and use content?
- ☐ Does tech avoid content that causes seizures or physical reactions?
- ☐ Does tech help users navigate and find content?
- ☐ Does tech make it easier to use inputs other than keyboard?

Understandable

- ☐ Does tech make text readable and understandable (e.g., visually impaired, color blindness settings)?
- ☐ Does tech make content appear and operate in predictable ways?
- ☐ Does tech help users avoid and correct mistakes?

Robust

- ☐ Does tech maximize its compatibility with current and future user tools such assistive technologies?

Example Standards

Computer-based Systems

World Wide Web Consortium (W3C)/ ISO 9241-210:2019[66,67]

Human-centred design principles and activities of computer-based interactive systems

- Blind / Low Vision
- Deaf / Hearing Loss
- Speech Disabilities
- Photo-sensitivity
- Learning Disability
- Cognitive Limitations
- Movement Limitations

User Interfaces

Information Technology Industry Council (ITI)[68]

VPAT 2.5

- *Section 508:* U.S. Federal accessibility standard
- *2.5 EU:* EN 301 549: Accessibility requirements suitable for public procurement of Information & Communication Tech (ICT) products in Europe

Tech Design

ANSI / AAMI[69]

HE75:

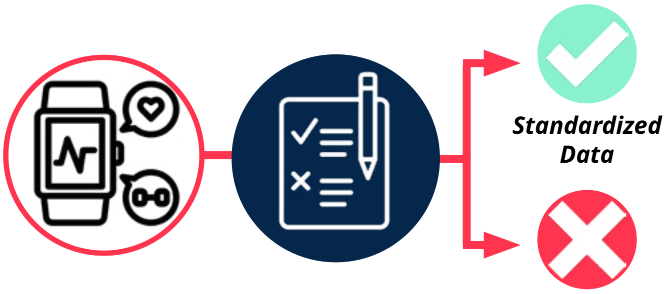
Human Factors Engineering (HE) device design principles for human capabilities and limitations (e.g., physical, sensory, emotional, and intellectual)

#20 Data Standardization

Definition: Data is presented, available in, and convertible to a standardized format(s) in line with conventions across a variety of contexts.

How to assess?

One method for assessing data standardization is ensuring data is available and convertible to standardized formats. The proposed checklist enables end-users to evaluate data format consistency, schema adherence, interoperability (see Feature #21), and compliance with industry standards, ensuring data remains structured and usable across systems.



Checklist

- ☐ **Data Formats:** Ensure data is stored in commonly accepted formats (e.g., CSV, XML, JSON).
- ☐ **Data Type Consistency:** Check for consistent use of data types (numeric, string, date).
- ☐ **Schema Conformance:** Verify if the data follows a specific schema (e.g., required fields, data types, and validation rules)
- ☐ **Interoperability:** Assess if the data formats meet interoperability requirements.
- ☐ **Industry Standards:** does data format and structure comply with industry standards (e.g., W3C for web data, Open Geospatial Consortium for spatial data)
- ☐ **Adherence to Naming Conventions:** Verify that the data uses consistent units (e.g., meters, seconds) and dimensions (e.g. data tables, outputs)

Example Standards

Sleep Monitors

DiMe[70]

Core Measures: Sleep Measurement System

General definitions and labeling of sleep stages such as; asleep, awake, light sleep, deep sleep, & REM sleep.

Human Subject Data

CTA / ANSI[71]

CTA-2060 R-2023:

Normative definitions for representing meta-data of different types of tech, including; time-series synchronization, event markers, eye gaze tracking, motion capture systems, raw & compressed video

Web-based Apps

W3C[72]

W3C Web Standards:

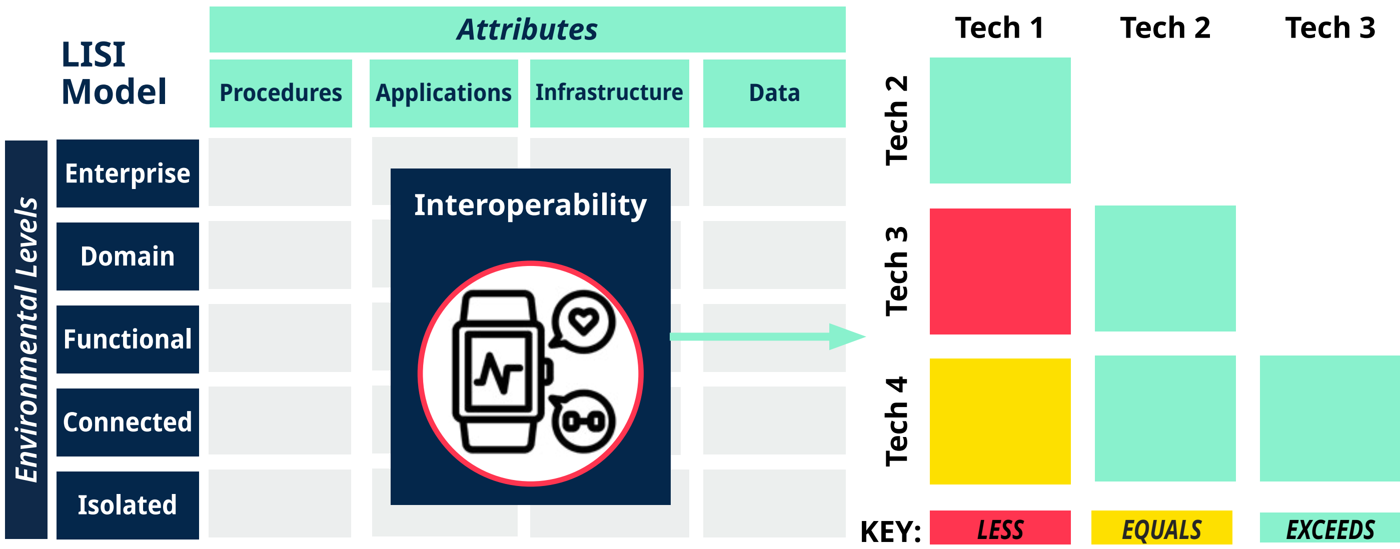
Resources and tools available to assist with site development that meet Web standards. This includes a validator service that checks the markup validity of Web documents in HTML, XHTML, SMIL, MathML, etc

#21 Interoperability

Definition: Ability of the tech to physically connect to and logically communicate with another set of entities at foundational, structural, or semantic levels.

How to assess?

Rezai et al.[73] reviews interoperability evaluation models, highlighting the Levels of Information Systems Interoperability (LISI) model as common method for assessing tech interoperability across five environmental levels and four attributes to generate an "Interoperability Profile" for comparison between different tech systems, rated as less, equal or exceeds expected interoperability.



Example Standards

Bluetooth

Bluetooth Special Interest Group[74]

Special interest group that oversees the development of

- Bluetooth standards
- Licensing of Bluetooth technologies
- Trademarking for manufacturers

Evaluation Models

Defence Technical Information Centre[75]*/ Peer-Reviewed Literature*[73]

LISI Model (above): Less, Equals, Exceeds expected

Stop Light Model (below)

Green	No known issues
Yellow	Does not meet requirements; no known issues.
Red	Does not meet requirements; known issues.
Orange	Meets requirements; known issues.

Tracking Tech

Open Geospatial Consortium (OGC)[76]

Geospatial standards for tracking technologies guide

Roles of decision-makers, developers, and users in implementing geospatial standards, including system compatibility and interoperability across organisations.

#22 Maintainability

Definition: Extent to which the system's functionality remains stable with minimal disruption to the end-user whilst being upgraded, maintained, or serviced

How to assess?

Modularity

☐ Are components easily replaceable or upgraded with minimal disruption?
☐ Can parts be swapped or maintained with minimal downtime?

Analysability

☐ Are tools or documentation available for quick issue diagnosis and resolution?
☐ Can support teams address problems efficiently without impacting users?

Changeability

☐ Can the system be updated or adapted while maintaining functionality?
☐ Does the system support firmware updates, software patches, or custom enhancements with minimal risk of causing disruption?

Testability

☐ Are methods in place to verify stability after updates or repairs?
☐ Can the system be reliably tested to ensure minimal downtime?

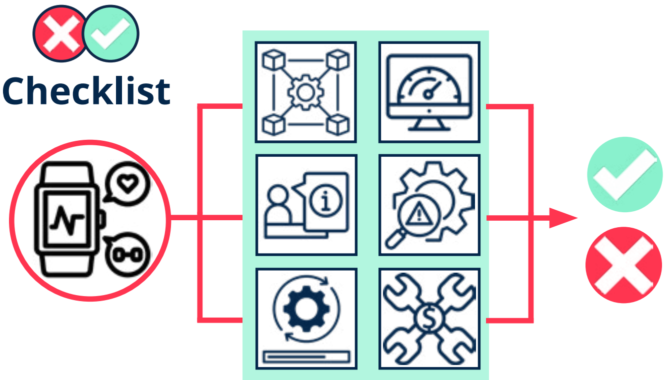
Troubleshooting

☐ Is there accessible documentation for minimizing disruption during maintenance?
☐ Is reliable support available to ensure system functionality during service?

Maintenance Cost

☐ Are maintenance costs clearly outlined and reasonable, with minimal surprises?

This checklist is adapted from standard ISO/IEC 25010:2023[77] to assist tech user evaluation of system and hardware stability during updates, maintenance, or system changes. Users can then establish whether minimal disruption to tech performance remains during its maintenance.



Example Standards

Information & Communication Tech (ICT)

ISO/IEC[77]

ISO/IEC 25010:2023: Quality model for maintainability characteristics - *Modularity, Reusability, Analysability, Modifiability, & Testability*

Software Systems

IEEE Xplore[78]

Maintainability Index (MI)

Software based standard whereby the higher the MI the more maintainable the system

Officiating Tech

ITF[9]

ITF Standards (A3.6)
Tennis Line-Calling Systems

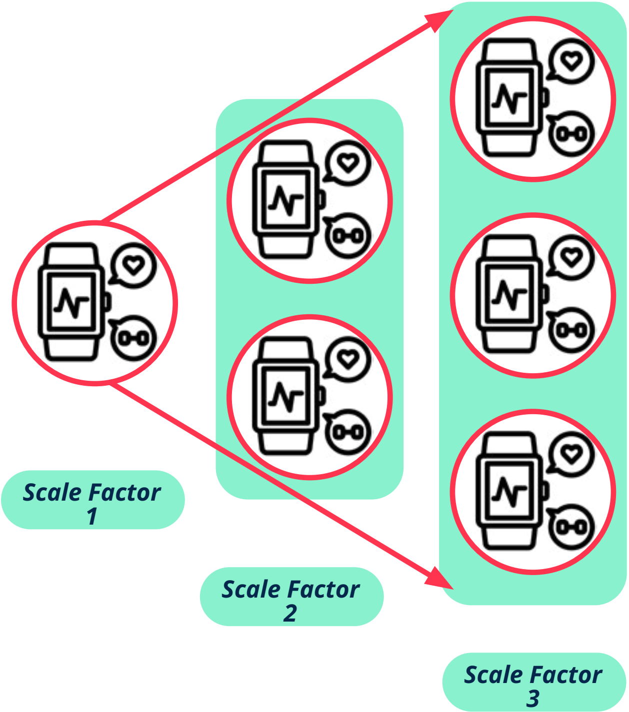
- Modular design for repairs, & quick failure correction
- Real-time backup and recalibration
- Embedded diagnostics, failure isolation, and protection from interference

#23 Scalability

Definition: The measure of a tech's ability to increase in performance and cost in response to changes in application and system processing demands.

How to assess?

The Scalability Metric by Jogalekar[79] is a suggested tool to evaluate a technology's ability to maintain productivity as a tech's scale changes, The metric considers factors like active users, database size, processors required, and ongoing running costs. Although sport tech-specific scalability metrics are unavailable, this tool can be used to assess the scalability of sport technology within an organisation.



Scalability Metric = Scale Factor 1 : Scale Factor 3

The scalability metric is the ratio between the tech productivity of a system at different scale factors. Productivity is measured at each scale factor and is expressed as

$$\frac{\textit{Value delivered by tech per second}}{\textit{Cost per second, number of responses processed per second}}$$

- *Value delivered:* based on how well tech performs under different levels of demand.
- *Cost at scale factor:* ongoing cost per second of operating demand or usage

Example Standards

Data Storage

IEEE[80]

IEEE 1285-2005:Standard for Scalable Storage Interface

Specifies a scalable interface between mass-storage devices and controlling hardware / software.

Media Streaming

ISO / IEC[81]

ISO/IEC 23009-1:2022:

Standard for adaptive bit-rate streaming of high-quality media content over the Internet via

- Adaptive streaming over HTTP resulting in standardisation of MPEG-DASH
- Standard for live streaming and broadcast

Software Performance

Peer-reviewed Literature[79]

Scalability Metric

Scale factors and optimised scalability metrics for connection management systems

Scale Factor	Scalability Metric
1	1.0
4	0.9
7	0.7

3. Framework operationalisation

Since its inception, the framework has been operationalised for decision-making within organisations in a variety of ways. Although it is likely too early in the framework's existence to state conclusively the efficacy of these models, some strengths and weaknesses of each are included below:

Table 2. Strengths and weaknesses of framework operationalisation models implemented by organisations.

Model	Definition	✔	✘
Pass/Fail	Decision to pass/fail or purchase/license is made based on the technology fulfilling a defined level of performance in some or all of the features.	✔ Facilitates fast decision-making. ✔ Useful in contexts where minimum requirements in certain features are essential (i.e., safety).	✘ Lacks detail. ✘ May not be suitable in mature tech fields where more detailed quality differentiation is required.
Gatekeeper	The tech is primarily assessed on a smaller subset of features. Only tech passing a set of initial criteria are progressed for further testing on other features.	✔ Pragmatic implementation of the framework. ✔ Time and resource efficient.	✘ Requires prior knowledge of the most important features to assess. ✘ Prone to bias.
Partial	Similar to the gatekeeper model, except that no further stages of assessment are undertaken and only the initial subset are tested.	✔ Good for less-resourced organisations or for collaboration whereby different departments or groups are analysing specific features or pillars.	✘ May miss crucial information as part of the tech selection process.
Integrated	Outputs from the framework are combined with existing systems or policies to inform a resulting decision. For example, a high quality system based on the framework may still be overlooked due to being cost prohibitive.	✔ Reflects real-world decision making. ✔ Future-focused, facilitating continuous iteration.	✘ More effort to implement thus requires longer term vision. ✘ Potential for other factors to be weighted disproportionately higher than quality.
Weighted	Relates to more heavily emphasising the importance of certain features of the framework over others.	✔ Can be used to validate the framework itself, thus increasing its value.	✘ Likely to be a time intensive and longitudinal process requiring trial and error.

4. Case study example

The FIFA Quality Programme for Electronic Performance Tracking Systems

The FIFA Quality Programme for Electronic Performance Tracking Systems (EPTS) was launched in 2017, prior to the development of this framework. From inception, it pursued multiple objectives with the initial aim to ensure that such systems did not pose a danger to players. In 2019, after extensive research, the Programme was extended beyond safety tests to include tests of accuracy for both optical and wearable devices, giving systems and commercial providers the chance to receive the 'FIFA Quality' certification. This introduction was made in an effort to provide the end user with more information about the system they are using or intending to use. Today all certified systems have their results[82] published on the FIFA website where the accuracy of the system's position and velocity data in different velocity brackets are described.

Certification test events are now conducted regularly (annually), and are open to any EPTS providers operating in football. Providers receive a certification lasting four years; however they are free to participate annually to improve their results should they wish. The test battery[83] consists of players conducting a variety of football specific movements in a stadium, with millions of data points collected at each event. Since 2019, a range of quality features have been added to the testing protocol of EPTS providers in addition to safety and accuracy (Figure 2 below). These additions have been made both to provide the end user with greater information on the quality of these systems and to further differentiate the growing number of commercial providers operating in this area. Although the testing of some of these features predates the Sports Tech Quality Framework, its inception has provided a readily adoptable template to help guide the further expansion of the FIFA EPTS Quality Programme in the coming years.

2017

Feature #5 Construct Validity:

Prior to commencement of the FIFA EPTS Quality Programme, a literature review was conducted to determine both the already realised and potential value which EPTS could provide for various applications across football performance. Whilst annual assessment of this feature at EPTS test events is not currently undertaken separately for each commercial provider, as the number of metrics reported by companies increases, some may wish to highlight this quality feature. For instance, in the event that a company provides ball tracking, gait analysis or technical measure detection (i.e., number of player passes) in addition to measuring velocity and position then they may wish to promote it to prospective end users.

Feature #12 Safety:

Initial medical and mechanical research along with an accompanying test protocol[83] was conducted reflecting possible injury scenarios that should be avoided. All EPTS devices must pass the safety testing to receive a 'FIFA Quality' mark.

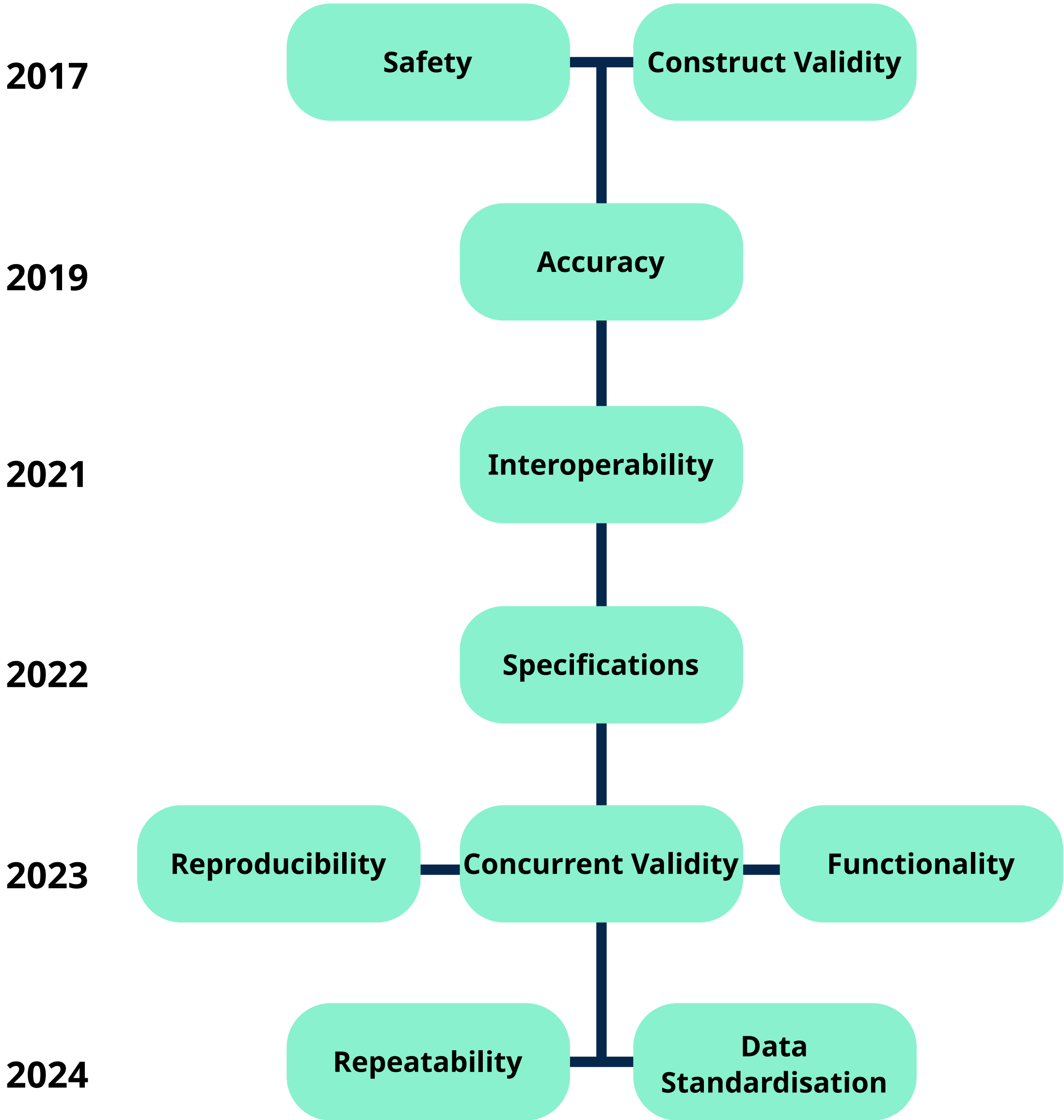


Figure 2. Time line showing the expansion of the FIFA EPTS Quality Programme from 2017 to 2024.

2019

Feature #1 Accuracy:

The first implementation of the current formal testing protocol of position and velocity accuracy was conducted in a football stadium. In the current protocol, each system is compared with a 3D motion capture system, which is typically recognised as the gold standard for such measures. Accuracy for providers is reported both on a continuous scale as well as an ordinal ranking, with providers rated as 'Well-above', 'Above', 'Average', 'Below-average' or 'Well below-average' relative to other providers operating in the space.

2021

Feature #21 Interoperability:

With the emergence of some providers providing 'live' (near real-time) data delivery, FIFA rolled out the option to assess this feature at EPTS test events should a company wish. This assessment is conducted through assessment of the latency of data delivery, which if deemed suitable for that device, opens the door for various applications not historically seen with EPTS (i.e., fan insights during television broadcast).

2022

Feature #4 Specifications:

Additions were made to existing reports to clarify the specific details of the systems tested by providers. Such information included the exact number and make of cameras used by optical systems, and the satellite conditions experienced by GNSS systems during testing. Prior to a report end-user making a decision to use a given system, it is important for them to be aware of whether the system they intend to acquire matches the one on the publicly-available report.

2023

Feature #3 Reproducibility:

Assessment of this feature is not yet a formal part of all EPTS testing, as it would substantially increase the cost of running the event (i.e., installation of optical systems at multiple venues). Despite this, research has been conducted by FIFA in collaboration with providers to assess this feature through determining the impact of different stadiums and cloud cover on system accuracy.

Feature #6 Concurrent Validity:

Whilst assessment of this feature is also not yet formally embedded in the programme, in some sessions multiple systems are assessed concurrently. For instance, an optical and GNSS system are unlikely to interfere with each other's signal when operating at the same time, thus it is possible to compare the output of both simultaneously. Other assessments undertaken have considered the effect of different placements of trunk-mounted and foot-mounted sensors comparative to Vicon in terms of accuracy.

Feature #8 Functionality:

2023 also saw the inclusion of testing female athletes in EPTS testing for the first time. Research has been conducted to investigate the utility of different GNSS sensor pocket locations to suit female bra and jersey designs and its subsequent impact on system performance.

2024

Feature #2 Repeatability:

Similar to reproducibility, this feature has not been assessed on each provider to date due to prohibitive costs. Despite this in 2024, one provider was assessed on two consecutive occasions one day apart in the same stadium against a reference system. Future iterations of testing may choose to include assessments of repeatability as more feasible and efficient methods of assessing it emerge.

Feature #20 Data Standardisation:

Work is currently underway with global collaborators to develop a Common Data Format (CDF) for EPTS, which would facilitate enhanced sharing, collaboration and help improve organisational efficiency.

2025 and beyond

In coming years, FIFA plans to expand the EPTS Quality Programme for EPTS to examine more of the remaining 13 features included in the Sports Tech Quality Framework, making it one of the most comprehensive assessments of such systems in world sport.

6. Next steps

Although this document adds substantial detail to the initial whitepaper, many other ideas, questions and requests have also been received since its release. The group remains committed to further progressing the framework through some of the initiatives mentioned below. Some of these works may manifest through further whitepapers, industry Summits or web-based resources. This work remains a non-profit, labour of love for those involved, and support is always welcomed. Please reach out to the group using the contact details below if you would like to contribute or be involved.

- A repository of guidance and available industry standards for each feature, similar to the Library of Human Factors Resources for Digital Health Technologies[84],
- Case studies, highlighting successes and lessons learned by end-users implementing the framework in practice, such as embedding the framework in grant or request for proposal submissions,
- Examples of framework validation, using one or more of the models outlined in the 'Framework Operationalisation' section. For instance:
  - How much assessment is enough for a start-up to warrant a minimum viable product (MVP)?
  - How different technology use cases dictates the assessment of certain feature sets,
- How to get buy-in for the framework in a sporting organisation?
- Who is responsible for implementing and maintaining the framework's operation?
- Various resources for organisational decision makers vs framework end users, who may differ in their motivations and literacy levels,
- Organisational self-assessment tools, for organisations looking to evaluate their current technology suite,
- Crowd-sourced, open access methods of maintaining the framework and adding new resources over time,
- Developing a database of experts whom framework users can contact when requiring deep expertise relating to a specific feature,
- How the framework itself may lead to new positions within sporting organisations, and how it can help to refine the nature of existing roles,
- Guidance around pre- framework implementation activities,including:
  - What are the aims for the technology application?
  - Which questions will it be used to answer?
  - Other than quality, which aspects need to be emphasised in decision making around its use (i.e., cost)?
- How to communicate return on investment internally around implementing and resourcing around the framework. This may include tools for working with both the marketing team and C-suite.

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