

ORIGINAL RESEARCH

Conceptual Technical and Commercial Feasibility of Biodegradable Silk-Based Electronic Systems

Ishan Saxena, Ronil Lahane*

Independent Researchers

**Corresponding author email: silkboundteam@gmail.com*

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Abstract

Electronic waste is a growing environmental and public-health concern, creating demand for electronic systems that reduce persistent waste. Silk fibroin has received attention as a flexible, biodegradable, bio-compatible, and processable biomaterial for electronic applications. In this conceptual feasibility study, we evaluate the potential use of silk fibroin within SilkBound, a proposed layered electronic system intended for temporary medical, wearable, and environmental applications. We combined findings from published research on silk-based and transient electronics with preliminary market evidence collected through a user survey. Technical feasibility was evaluated based on material function, electrical integration, flexibility, mechanical durability, moisture sensitivity, thermal stability, reliability, device lifespan, degradation control, and manufacturing requirements. The preliminary survey was used to identify possible adoption drivers and barriers and is reported with its methodological detail. Existing research supports the use of silk fibroin as a substrate, dielectric, encapsulation material, and, in some systems, a functional electronic component. However, the feasibility of SilkBound as a complete device cannot yet be confirmed because an integrated prototype has not been fabricated or tested. The concept appears most promising for specialized temporary applications in which flexibility and controlled degradation offer clear advantages over conventional materials. Future research should identify an initial application, select compatible materials, fabricate a prototype, and evaluate performance, degradation, safety, environmental impact, manufacturing scalability, and cost.

Keywords: silk fibroin; biodegradable electronics; transient electronics; flexible electronics; electronic waste; wearable sensors; commercial feasibility

1. Introduction

Electronic waste, or e-waste, is one of the fastest-growing solid-waste streams worldwide. Electronic products contain valuable materials that can be recovered, but they may also contain substances capable of harming human health and the environment when discarded or processed improperly (World Health Organization [WHO], 2024). Conventional electronic systems are generally designed to maintain long-term performance. Although this durability is essential for products expected to operate for several years, it may be unnecessary for devices intended for temporary use. Disposable sensors, short-term medical devices, wearable monitors, and environmental sensing systems may remain as waste long after

completing their intended functions.

Transient and biodegradable electronics represent a possible response to this problem. These systems are designed to operate for a defined period and subsequently dissolve, degrade, or physically disintegrate under specified conditions. Previous research has demonstrated transient electronic components incorporating degradable substrates, conductors, dielectrics, semiconductors, sensors, and power-related components (Hwang et al., 2012). However, incorporating one biodegradable material does not make an entire electronic system biodegradable. The environmental behavior of every major component must be considered.

Silk fibroin is a naturally derived protein obtained primarily from silkworm cocoons. It can be processed into films, fibers, coatings, gels, and porous structures. Its mechanical strength, water solubility, flexibility, optical properties, and degradation behavior can also be modified through processing (Wen et al., 2021). We developed SilkBound as an early-stage venture concept that explores the use of silk fibroin within a layered electronic system. We do not assume that silk can replace every material in an electronic device. Instead, we examine whether silk could function as a substrate, dielectric, encapsulation layer, or supporting material while other components perform conductive, semiconducting, or sensing functions.

This paper evaluates the conceptual technical and commercial feasibility of SilkBound by asking three questions: (1) What functions could silk fibroin realistically perform within an electronic device? (2) Which technical barriers must be resolved before a SilkBound device could be considered feasible? and (3) Which applications are most likely to provide a meaningful commercial reason to use a silk-based system?

2. Methods and Scope

We used a conceptual feasibility approach that combines a narrative review of published research with preliminary evidence from our user survey. Because the literature review was narrative rather than systematic, it was intended to assess conceptual plausibility and was not designed to identify every relevant publication. For the literature review, we examined research involving silk fibroin, flexible electronics, transient electronics, bioresorbable systems, wearable sensors, and temporary environmental or biomedical devices. We focused particularly on demonstrated uses of silk as a substrate, supporting layer, dielectric material, encapsulation layer, and functional material.

2.1 Survey recruitment and participants

The exploratory survey received more than 100 responses. Participants were recruited through direct sharing. The survey was administered through Google Forms from August 1 to September 1. Participation was voluntary and anonymous. No personally identifying or sensitive information was intentionally collected. The respondent pool included no collected demographic characteristics, as the survey focused primarily on participants' attitudes toward sustainability, biodegradable electronics, cost, durability, reliability, and willingness to consider temporary electronic products rather than demographic comparisons. Because recruitment used a non-probability convenience approach, the sample should not be interpreted as representative of consumers generally.

2.2 Survey instrument and response scales

The survey was designed to explore attitudes toward sustainable and biodegradable electronics rather than to estimate population-level demand. Questions addressed sustainability, willingness to consider biodegradable electronics, price sensitivity, durability and reliability expectations, and possible applications. Table 1 reproduces the exact survey wording and response options so that readers can independently evaluate how the reported patterns were generated.

Table 1. Survey Questions and Response Options

Item	Exact survey question	Response options / scale	Variable used in analysis
1	How interested are you in electronic products designed to reduce environmental waste or improve sustainability?	Very Interested Interested Somewhat interested Slightly interested Not interested	Sustainability interest
2	How willing would you be to consider using a biodegradable electronic product if it provided similar functionality to a conventional electronic product?	Very willing Willing Unsure Unwilling Very unwilling	Adoption / purchase interest
3	How would price affect your willingness to consider a biodegradable electronic product compared with a conventional alternative?	I would be willing to pay significantly more I would be willing to pay slightly more I would prefer it to cost about the same I would only consider it if it were cheaper I would not consider purchasing it regardless of price	Price sensitivity
4	Which of the following best describes your main concern about the durability of a biodegradable electronic device?	It may break or wear out too soon It may not remain functional for its full intended period of use It may be damaged by moisture or environmental exposure I would be less concerned about durability if the device were intended only for short-term use I do not have significant durability concerns	Durability concern
5	Which of the following would be your greatest concern about the reliability of a biodegradable electronic device?	It must work consistently throughout its intended period of use It may produce inaccurate measurements or readings It may fail unexpectedly I would want evidence or testing showing that it works reliably I do not have significant reliability concerns	Reliability concern
6	Which application for biodegradable or temporary electronic devices would interest you the most?	Temporary health-monitoring sensors Environmental sensors Agricultural sensors Smart packaging Wearable health devices	Preferred application

2.3 Survey analysis

Responses were summarized using descriptive statistics. For each closed-ended item, we calculated the number and percentage of respondents selecting each response option using:

$$\text{percentage} = \left(\frac{\text{number selecting the option}}{\text{total valid responses to that item}} \right) \times 100$$

For descriptive comparisons, respondents who selected “Very interested” or “Interested” for the sustainability-interest question were grouped as having higher sustainability interest, while respondents select-

ing lower-interest categories were considered separately. Comparisons between response groups were descriptive unless a formal statistical test was actually conducted. No causal conclusions were drawn from associations between survey responses.

There were no missing or skipped responses in the survey data. Because this was an exploratory survey, we did not use probability sampling or claim that observed percentages generalize beyond the respondents who completed the survey.

2.4 Scope limitations

We have not yet fabricated a prototype or conducted laboratory testing, clinical testing, an environmental lifecycle assessment, or a complete manufacturing-cost analysis. Our conclusions therefore concern the plausibility of the concept and priorities for future development rather than confirmed product performance. The survey likewise provides exploratory market evidence only and is not treated as definitive evidence of commercial demand.

3. Silk Fibroin in Electronic Systems

3.1 Material Characteristics

Silk fibroin can be processed into multiple forms and combined with other materials to create composite structures. Its biodegradability and water solubility can be adjusted partly through changes in its molecular structure and processing conditions. Increased beta-sheet content generally improves mechanical stability and reduces water solubility, allowing researchers to influence the relationship between durability and degradation (Wen et al., 2021). Silk fibroin also offers flexibility, low weight, optical transparency, and biocompatibility. These characteristics have supported its investigation in wearable devices, implantable electronics, sensors, energy-harvesting systems, and temporary electronic platforms.

Environmental sensitivity presents both an opportunity and a challenge for the proposed system. Silk's response to water and humidity may enable controlled dissolution, but it could also cause premature loss of performance. The device would therefore need to remain stable during operation and degrade only under appropriate end-of-life conditions.

3.2 Appropriate Role of Silk

We do not describe silk fibroin as a universal replacement for silicon or other semiconductor materials. Depending on its preparation and the device architecture, silk may function as a flexible substrate, insulating or dielectric layer, encapsulation material, temporary structural layer, sensing or environmentally responsive component, or part of a composite functional material.

Research has demonstrated ultrathin electronic systems supported by dissolvable silk films. After the silk substrate dissolved, the remaining electronics formed conformal contact with biological tissue (Kim et al., 2010). Other researchers have demonstrated transient silicon-based systems that use silk as a substrate or packaging material alongside degradable metals and dielectrics (Hwang et al., 2012). Researchers have also developed silk-based bio-transient memory devices with programmable operating lifetimes (Yong et al., 2017). These demonstrations support continued investigation of SilkBound, although they do not establish that the proposed system will perform successfully.

4. Proposed SilkBound Architecture

We propose SilkBound as a layered system containing a silk fibroin substrate, a functional sensing or semiconductor layer, conductive electrodes, and a protective coating. The exact material combination would depend on the application selected.

4.1 Silk Fibroin Substrate

The silk fibroin substrate would serve as the structural base of the device, supporting the electronic layers while contributing flexibility, low weight, and controlled degradation. Substrate thickness, molecular

structure, mechanical strength, and dissolution rate would need to be selected according to the operating environment.

4.2 Functional Layer

A separate functional material would perform the primary sensing, switching, or signal-processing function. Selection of this material would affect electrical performance, toxicity, environmental impact, and compatibility with the silk substrate. SilkBound is therefore described as a silk-based electronic system rather than an electronic device made entirely from silk.

4.3 Conductive Electrodes

The device would require conductive electrodes to transmit electrical signals between components. Electrode materials would need adequate conductivity, adhesion, flexibility, and stability throughout the intended operating period. If complete biodegradability or bioresorption is pursued, the degradation behavior and toxicity of the electrode materials would also need evaluation.

4.4 Protective Coating

A protective layer could limit exposure to water, humidity, physical damage, or biological fluids. Its purpose would be to prevent premature degradation while allowing the device to break down after completing its intended function. A persistent coating could interfere with degradation, whereas an insufficient coating could allow premature failure.

4.5 Power and Data Management

A complete SilkBound system would require a source of power and a method of transmitting or storing information. Depending on the application, options could include an external reader, wireless communication, passive sensing, energy harvesting, or a limited-duration power source. These components must also be included in any complete environmental assessment.

5. Potential Applications

5.1 Temporary Medical Sensors

Temporary medical sensors could monitor temperature, pressure, moisture, movement, or other biological signals during a defined treatment or recovery period. Silk fibroin's flexibility and ability to conform to irregular surfaces may be valuable for devices placed on the skin or near biological tissue. Medical use would require evaluation of biocompatibility, sterility, measurement accuracy, degradation products, clinical benefit, and regulatory requirements.

5.2 Wearable Health Devices

Silk-based wearable sensors could provide lightweight and flexible monitoring for uses that do not require permanent hardware, including short-term motion, pressure, hydration, or temperature monitoring. Commercial value would depend on whether silk provides a measurable advantage in comfort, conformability, disposal, or environmental impact without unacceptable reductions in performance or increases in cost.

5.3 Environmental Sensors

Temporary environmental sensors could monitor soil conditions, temperature, humidity, or pollution in locations where collection is difficult. Safe degradation after use could reduce retrieval requirements and persistent waste. However, environmental deployment would expose the device to moisture, heat, sunlight, and physical stress, making durability and degradation control critical.

6. Technical Feasibility

6.1 Electrical Performance

The SilkBound system would need to provide stable electrical behavior throughout its intended operating period. Future testing should evaluate signal quality, conductivity, sensitivity, measurement accuracy, and changes in performance during bending, temperature variation, moisture exposure, and progressive degradation. Because no integrated prototype has yet been fabricated, electrical feasibility remains a hypothesis rather than a demonstrated result.

6.2 Flexibility and Mechanical Integrity

Silk fibroin may provide a flexible supporting platform, but the complete device would need to tolerate bending and movement. Electrodes, functional layers, interfaces, and coatings could crack or separate even if the silk substrate remained intact. Tensile, bending, fatigue, adhesion, and handling tests would therefore be necessary.

6.3 Moisture Stability

Moisture sensitivity is one of the most significant design challenges. Wearable devices may contact sweat, medical devices may encounter biological fluids, and environmental sensors may experience rain or humidity. The design must balance water resistance during use with controlled degradation after use. Moisture-triggered transient electronics demonstrate that environmental exposure can initiate degradation, but timing and chemistry must be carefully engineered (Gao et al., 2017).

6.4 Thermal Stability

Device materials would need to remain stable within expected operating and storage temperatures. Heat generated by components or encountered in the environment could alter the silk structure, affect protective coatings, or change electrical performance. Both short-term heat exposure and repeated temperature cycling would require evaluation.

6.5 Reliability and Functional Lifespan

A biodegradable device must remain reliable long enough to complete its intended function. Required lifespan should be defined before selecting materials because a device intended for hours of operation requires a different architecture from one expected to function for weeks. Reliability testing would need to establish acceptable failure rates and determine whether performance remains within defined limits.

6.6 Controlled Degradation

Degradation must occur at an appropriate rate and under defined conditions. Premature degradation could cause device failure, while delayed degradation could reduce the intended environmental advantage. The complete system, rather than only the silk substrate, would need to be evaluated for degradation products, persistence, toxicity, and environmental benefit.

6.7 Manufacturing and Scalability

Commercial feasibility would require consistent silk films and reliable integration with functional materials. Variations in film thickness, crystallinity, moisture content, surface properties, or processing conditions could alter device performance. Repeatability, material yield, production time, quality control, compatibility with fabrication methods, and cost must therefore be evaluated before commercial scalability can be established.

7. Preliminary Survey Results

The survey results are presented as exploratory evidence only. This section separates the observed response distributions from broader interpretations about market demand. Readers should evaluate Table 2 together with the exact survey wording and response scales reported in Table 1.

Table 2. Survey Response Distributions ($N = 120$)

Survey variable	Response category	n	%	Interpretation permitted by the data
Sustainability interest	Very Interested	38	31.7%	Describes how respondents rated sustainability.
	Interested	42	35.0%	
	Somewhat Interested	25	20.8%	
	Slightly Interested	10	8.3%	
	Not interested	5	4.2%	
Willingness to consider biodegradable electronics	Very Willing	28	23.3%	Describes stated willingness among this sample.
	Willing	47	39.2%	
	Unsure	30	25.0%	
	Unwilling	11	9.2%	
	Very Unwilling	4	3.3%	
Price sensitivity	Would pay significantly more	5	4.2%	Describes price concern among this sample.
	Would pay slightly more	31	25.8%	
	Prefer same price	54	45.0%	
	Only consider if cheaper	27	22.5%	
	Would not consider regardless of price	3	2.5%	
Durability concern	May break/wear out too soon	39	32.5%	Describes concern that biodegradable products may be less durable.
	May not last full intended use	28	23.3%	
	Moisture/environmental damage	27	22.5%	
	Less concerned for short-term use	18	15.0%	
	No major durability concern	8	6.7%	
Reliability concern	Must work consistently	44	36.7%	Describes expectations for dependable performance.
	Concerned about inaccurate readings	26	21.7%	
	Concerned about unexpected failure	24	20.0%	
	Wants evidence it works reliably	22	18.3%	
	No major reliability concern	4	3.3%	
Preferred application	Temporary health-monitoring sensors	40	33.3%	Describes which proposed use case received the most selections.
	Environmental sensors	32	26.7%	
	Agricultural sensors	21	17.5%	
	Smart packaging	17	14.2%	
	Wearable health devices	10	8.3%	

Of the 120 respondents, 38 (31.7%) selected “Very interested” for the sustainability item, while 42 (35.0%) selected “Interested.” Together, 80 respondents (66.7%) were classified as having higher sustainability interest. These results indicate the distribution of sustainability attitudes within the sample but do not establish how the broader population would respond.

For willingness to consider biodegradable electronics, 47 respondents (39.2%) selected “Willing”, while 28 respondents (23.3%) selected “Very willing.” Together, 75 respondents (62.5%) expressed positive willingness to consider biodegradable electronics. Price, durability, and reliability responses are reported in Table 2. Rather than stating that respondents would categorically reject reduced performance, we interpret these items more narrowly: the distribution of responses shows the extent to which cost, durability, and reliability were concerns among the surveyed participants.

For descriptive comparison, respondents selecting “Very interested” or “Interested” on the sustainability question were classified as having higher sustainability interest, while all remaining respondents

were classified as having lower or moderate sustainability interest. Of the 80 respondents in the higher-sustainability group, 58 (72.5%) selected either “Very willing” or “Willing” to consider biodegradable electronics. Among the remaining 40 respondents, 17 (42.5%) selected either “Very willing” or “Willing.” This descriptive comparison suggests that greater sustainability interest was associated with greater willingness to consider biodegradable electronics within this sample, although no causal relationship can be established.

The survey also suggested a communication challenge surrounding the term “biodegradable.” Because no survey item directly measured this perception, we present it as a hypothesis for future customer discovery rather than a measured survey result.

8. Commercial Feasibility

SilkBound’s potential commercial advantage is its combination of flexibility, controlled degradation, low weight, and reduced persistent waste. These features are most likely to be valuable when a device is needed temporarily and conventional disposal or retrieval creates a specific problem. Potential customers could include medical-device companies, wearable-technology developers, environmental-monitoring organizations, research institutions, and companies seeking more sustainable disposable sensors.

This survey analysis does not treat consumer interest alone as proof of market demand. Instead, the response distributions identify questions that should be tested in future customer discovery, including acceptable price, expected durability, reliability requirements, and which applications provide enough value to justify a biodegradable system. Temporary medical and environmental sensors remain conceptually promising, but each market has distinct technical, regulatory, and customer requirements.

A practical market-entry process would include selecting a specific use case and customer; defining required operating lifespan and performance; comparing SilkBound with an existing alternative; identifying acceptable cost and performance thresholds; fabricating and testing an application-specific prototype; evaluating safety, degradation, manufacturing, and regulatory requirements; and repeating customer discovery using a prototype and realistic pricing. Institutional buyers, clinicians, engineers, regulators, manufacturers, and purchasing decision-makers may prioritize different requirements from those represented by the preliminary survey.

9. Limitations

This study evaluates SilkBound as an early-stage concept rather than a validated device. We have not fabricated an integrated prototype or conducted original electrical, mechanical, thermal, moisture, safety, or degradation testing. The technical assessment therefore relies on published research involving related silk-based and transient electronic systems.

The preliminary survey provides exploratory evidence about possible adoption drivers and barriers, but it does not establish market demand across a broader population. Its limitations include non-probability recruitment, a respondent pool that may not represent actual purchasers or institutional decision-makers, and the absence of validated measurement scales or complete inferential statistical testing. This paper reports the survey instrument, response options, recruitment method, and descriptive response distributions so that readers can more directly evaluate the evidence.

We also have not conducted a lifecycle assessment or complete manufacturing-cost, regulatory, reimbursement, and intellectual-property analyses. Future research should address these areas to determine whether SilkBound can provide measurable technical, environmental, and commercial advantages over existing electronic systems.

10. Conclusion

Published research supports the broader technical plausibility of using silk fibroin in flexible and transient electronics. Silk has been demonstrated as a substrate, dielectric, encapsulation material, supporting

layer, and functional component in several experimental systems. Its processability, flexibility, biocompatibility, and adjustable degradation behavior make it a credible material for continued investigation.

However, the feasibility of SilkBound as a complete product has not yet been demonstrated. Performance will depend on the functional layer, electrodes, protective coating, power strategy, data-transmission method, manufacturing process, and intended operating environment. The preliminary survey can help identify commercial hypotheses, but its results should be interpreted as descriptive of the surveyed sample rather than as evidence of population-level market demand.

The next step should be to select one clearly defined application and produce an initial prototype with measurable performance requirements. Technical testing, lifecycle evaluation, manufacturing analysis, and application-specific customer discovery would then help determine whether SilkBound can progress from a plausible concept to a commercially viable technology.

Funding Sources

We received no external funding for this study.

Conflicts of Interest

We developed the SilkBound concept and therefore have an interest in its potential future development. We declare no other conflicts of interest.

Ethics Statement

We conducted the survey independently as anonymous, voluntary preliminary market and concept research without affiliation with a school or research institution. We did not intentionally collect personally identifying or sensitive information, and we report the findings only as exploratory evidence. No institutional ethics review was obtained.

Consent to Participate

Participation was voluntary. By choosing to complete the anonymous survey, participants indicated their consent to participate.

Data Availability

The survey data are not publicly available because they may contain information that could compromise participant privacy. The survey instrument is available from the corresponding author upon reasonable request.

Author Contributions

Ishan Saxena drafted Sections 1–5, and Ronil Lahane drafted Sections 6–10. We jointly developed the SilkBound concept and research questions, reviewed and revised the manuscript, and approved the final version.

Use of Generative Artificial Intelligence

We used OpenAI's ChatGPT to assist with language editing, organization, and manuscript formatting. It was not used to collect survey data, perform the research analysis, or determine the study's conclusions. We reviewed and edited the complete manuscript and accept full responsibility for its accuracy and content.

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