Animal Welfare as a Missing Dimension of Smart Cities: A Software Engineering Perspective

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***Abstract*—Smart city initiatives are increasingly evaluated against sustainability metrics, yet the impact of digital infrastructures on non-human animals remains systematically overlooked. This paper argues that animal welfare constitutes a measurable, engineering-relevant dimension of smart city sustainability. We report state-of-the-art evidence of software-related harms to animals, from smart farming platforms to IoT sensor networks, and introduce a scope-based classification framework applicable to Software Development Life Cycles (SDLCs). We outline practical guidelines for software engineers and city planners with the aim of broadening the sustainability agenda of the research community.**

***Index Terms*—Smart Cities, Sustainability, Animal Welfare, Software Engineering Ethics, SDLC, IoT, Digital Farming.**

I. Introduction

Smart cities deploy complex digital systems (IoT sensor networks, data platforms, traffic management tools, smart farming applications) to improve urban efficiency and quality of life. Sustainability is central to smart city discourse, and the ICT sector has made measurable progress in addressing energy consumption, carbon footprints, and e-waste. However, one category of impact remains almost entirely unaddressed: the effect of urban digital systems on non-human animals [1], [2]. This is not a marginal concern. Urban areas host millions of animals (wild, feral, and managed) whose habitats and behaviours are directly affected by digital infrastructure. Smart city IoT deployments, drone fleets, data centre construction, and smart farming platforms all interact with the biological systems that animals depend on. Yet current sustainability frameworks for smart cities do not include animals as sentient stakeholders.

This work bridges software engineering and smart city research to argue that animal welfare is a measurable, actionable dimension of digital sustainability. We present state-of-the-art evidences, a structured classification framework, and concrete recommendations for practitioners.

II. Software-Related Animal Harm

A. Smart Farming and Digital Livestock Platforms

Smart farming is among the fastest-growing IoT application domains in urban and peri-urban areas. Sensor networks, predictive analytics, and automation platforms are commercially deployed to monitor and control farmed animals at scale. Research shows that these systems restructure the farmer's role from caretaker to data supervisor, reducing direct human-animal contact and reinforcing utilitarian treatment of animals [3], with requirements defined almost exclusively in terms of productivity metrics.

B. Drones and UAV Systems

UAV and drone systems, widely adopted in smart city contexts for surveillance, delivery, and environmental monitoring, have been shown to cause measurable behavioural disruption in urban wildlife. Empirical studies document stress responses, nest abandonment, and altered migration patterns in bird populations exposed to drone operations [4], [5]. These effects are predictable and preventable at the software level (through flight path planning, altitude constraints, and time-of-day restrictions) yet current drone software stacks do not include wildlife impact as a design parameter.

C. Data Centre Infrastructure

Smart city backends rely on large-scale data centres. A growing body of evidence links data centre land use, water consumption, and electromagnetic emissions to habitat loss and biodiversity reduction in surrounding areas [6], [7], and McKinney's meta-analysis of over 100 studies found that species richness decreases consistently with urban expansion driven by infrastructure development [8]. IoT platform growth in smart cities amplifies this effect.

D. Biologging and Animal Tracking Devices

Smart city environmental monitoring increasingly relies on biologging devices attached to animals (GPS trackers, migration sensors, soundscape microphones). While these tools produce valuable ecological data, peer-reviewed studies document physical burden and reduced survival rates in instrumented animals [9], and data collection software rarely accounts for this welfare cost.

E. Mobile Applications and Consumption Normalisation

Consumer-facing mobile applications embedded in smart city platforms (food delivery services, restaurant finders, marketplace apps) actively shape consumption choices. Recent empirical work demonstrates that choice architecture in such apps significantly influences users toward or away from animal-derived products [10], giving recommendation algorithms and default options measurable behavioural impact at population scale.

III. A Scope-Based Classification Framework

To support systematic reasoning about animal-related impacts in smart city software projects, we adapt the scope model of the Greenhouse Gas (GHG) Protocol [11] and ISO 14064 to the domain of non-human animal welfare. The framework classifies impacts into three scopes, mappable to SDLC phases:

TABLE I: Extended Framework: Mapping Animal Welfare Impacts and Intervention Points Across the SDLC

Scope	SDLC Phase	Identified Risks and Environmental Impacts	Software Engineering Interventions
Scope 1	*Requirements*	Algorithmic utilitarianism; reducing living animals to purely productivity-driven data points.	Integration of specific biological and welfare Non-Functional Requirements (NFRs); creating User Stories tailored for "non-human stakeholders".
(Direct)	*Design*	Software architectures and interfaces that disregard the emotional/physical state of animals (e.g., in Smart Farming).	Establishing ethical review checklists; adopting Animal-Centered Design (ACD) methodologies.
Scope 2	*Implementation*	High computational workloads and data center energy consumption leading to local habitat destruction.	Code optimization to minimize processing footprints (Green Coding); limiting radio frequency and EMF emissions.
(Indirect)	*Operations*	UAV/drone collisions with birds; severe audio-visual disruption affecting wildlife mating and migration.	Implementing dynamic geofencing (no-fly zones) and scheduling flight operations around local biological cycles.
Scope 3	*Planning*	Selecting cloud infrastructure providers with high carbon footprints and opaque sustainability reporting.	Executing rigorous Life Cycle Assessments (LCAs); defining software acceptance criteria based on vendor sustainability indexes.
(Systemic)	*Procurement*	E-waste accumulation and heavy metal toxicity from hardware deployment poisoning surrounding ecosystems.	Introducing ethical hardware procurement protocols; embedding mandatory supply-chain impact disclosure clauses.

- **Scope 1 – Direct harm:** Software designed to control or exploit animals as its primary function (e.g., precision livestock management platforms, wildlife capture coordination tools). These impacts are introduced at the requirements and design phases of the SDLC.
- **Scope 2 – Indirect environmental disturbance:** Impacts on animals arising from the operation of software systems not designed to interact with animals: data centre energy use, drone flight paths, IoT network electromagnetic emissions. These manifest primarily during implementation and operation.
- **Scope 3 – Delegated and supply-chain impacts:** Harms embedded in third-party components, cloud services, hardware procurement, and AI model training pipelines. Particularly relevant during planning and platform selection. These are the hardest to quantify but represent a significant share of the total impact.

The three scopes are not mutually exclusive, and welfare-related concerns typically recur across several SDLC phases rather than originating in just one. We therefore intend the scope-phase association as a conceptual lens for locating tractable interventions, not a strict allocation of responsibility; Table I illustrates one such mapping, with phase boundaries understood to be porous in practice.

IV. Recommendations for Practitioners

Based on the evidence and framework above, we propose four actionable steps for software engineers and smart city planners:

1) Introduce animal welfare as a non-functional requirement (NFR), alongside existing NFRs for energy consumption and carbon intensity.
2) Embed wildlife impact assessment in drone and IoT deployment procedures, using geofencing and time-based constraints already available in commercial flight management software.
3) Adopt supplier transparency requirements for Scope 3 impacts, analogous to existing carbon disclosure practices.
4) Include animal welfare impact as an acceptance criterion in sprint reviews for agile teams developing smart city applications.

A recent pre-survey conducted within the software engineering community found that only 16.4% of 280 respondents explicitly mentioned ethical considerations, and even then the ethical horizon remained strongly anthropocentric [12]. Smart city conferences and standards bodies have an opportunity to close this gap.

V. Limitations and Future Works

This work centers on software-related harms; we acknowledge, however, that software can also generate positive outcomes for animals, e.g., wildlife conservation platforms, biodiversity monitoring, early livestock disease detection, anti-poaching systems, and conflict-reducing smart-city designs. Raising practitioners' awareness of both harmful and beneficial impacts across the SDLC may be the more general, actionable objective, situating this work within the broader sustainability- and ethics-oriented software engineering agenda.

Future work will focus on quantitative metrics for animal impact reporting, building on the Value of Statistical Life (VSL) methodology adapted for non-human animals, and on empirically testing the cross-phase, non-exclusive nature of the proposed scopes.

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