



Functional Density: Why Intelligent Architecture Definition Matters



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The surgical robotics companies we partner with are constantly looking to squeeze greater functionality into ever-smaller form factors, a combination I'll call functional density. Our partners understand that functional density is critical to success in a competitive market, where form-factor influences clinical adoption (e.g., Is there room in the hospital? Does it obstruct workflow?) and functionality directly impacts clinical outcomes (e.g., capability of instruments, energy and visualization). The baseline of what hospitals and surgeons expect is constantly increasing as device companies push these boundaries. The devices that break new ground, exceeding function or form, have a critical differentiator in the eyes of customers.

From the perspective of the hospital buyers, introducing surgical robots into existing operating rooms and storage spaces poses novel challenges, which discourages the adoption of large footprint robots that may hinder workflow and occupy extensive storage space. Yet surgeons expect greater functionality, particularly for high-acuity procedures: instrument performance, improved feedback, integration with advanced energy systems, and access to AI augmentation.

This tension — shrinking form factor while expanding capability — is driving the need for functional density and will play an important role for future winners in surgical robotics.

Advances in materials, actuator power density, embedded sensing, and novel manufacturing processes support functional density. However just adding or optimizing technologies can only get you so far. The greatest impact on functional density is made early in the surgical robot development process when defining the system architecture. Failure to recognize this, and the cascading impact of early architectural decisions, is a common pitfall, but one that can be avoided with the right expertise and experience.

Intelligent architecture

The greatest impact on functional density is achieved with intelligent system architecture. Intelligent architecture prioritizes clinical value by only including features and functions necessary to maximize clinical outcomes and ensuring they are electromechanically implemented in a manner that reduces friction to clinical adoption. Without intelligent architecture, you might create a capable system, but it won't have a feature set that really catches the eye of users and enables them to do more. Here are three areas we think about when creating an architecture for functional density:

Clinical insights that ensure focus and eliminate functionality that doesn't add value.

Insights that provide critical clinical context inform the range of motion required to access the necessary anatomy, the resolution of each joint to give instruments the proper control, the dimensions and layout of the operating theatre to inform workflows, and many other critical elements of the system.

Knowing the clinical context inside out before putting pen to paper to design system architecture is imperative.

Deep understanding of clinical context guides what an architecture needs, or more importantly, what it doesn't need; striking the correct balance significantly improves the clinical value the architecture can deliver through functional density.

Front-end Insights teams can build and refine this deep understanding of clinical context by capturing insights early and often, through discussions with key opinion leaders and structured interviews with clinical stakeholders to build robust requirements and simplify decision-making. Throughout development, and as our working hypotheses mature, frequent testing and feedback serve to validate decision-making, allowing early course correction or doubling down to ensure clinical value is always the priority.

Optimizations that have nonlinear impacts on clinical value.

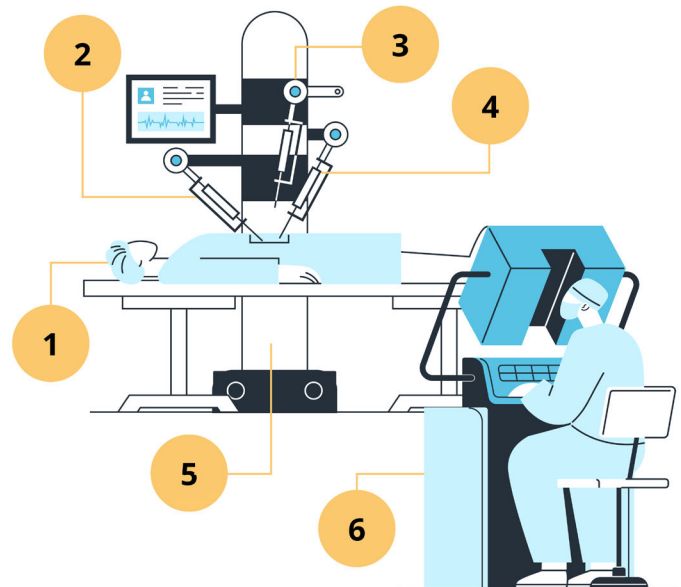
Consider the motors that drive laparoscopic instruments. Working volume, lifting capacity and end effector capability are all impacted by motor selection. Motors also significantly drive the form factor of the instrument and drive unit, so there is a clear trade-off between the size and capability of the instrument. Here, a step change in clinical impact could be realized by increasing motor specification to drive a high torque instrument, (e.g. a stapler), which unlocks a suite of procedures for a minimal increase to drive unit size, making it a good trade-off for functional density.

Besides selecting which features and functions make up the architecture, there's also a quantitative element of 'how much' of those features or functions are implemented (e.g., the reach and range of the robot, the torque output of instrument drive motors, or the resolution of force sensors). The key to optimizing the quantity of a function is a deep understanding of the relationship between the 'cost' of scaling the function versus the clinical value. There may be critical inflection points where step changes in clinical value can be unlocked as you increase or decrease functionality, and conversely, there are step changes in cost that don't add meaningful value. Recognizing the inflection

points is key to enabling significant, non-linear impacts to functional density and clinical value.

Multi-disciplinary input that maximizes the potential of how technology is selected and integrated.

Think about the many different elements of a surgical robot: mechanical linkages, drive units, resposable instruments, vision systems, advanced energy, disposable draping, etc. Now compound this with all the different ways of achieving those functions, and you quickly discover how broad a pool of expertise is needed to understand which technologies are available, how to use them and which ones are best suited for each of those elements.



1 Clinical Needs & Insights
Robin Huedepohl



2 Drape Systems
Sukie Whitehall



3 Robotic Drive Systems
James Boonzaier



4 Disposable/Reusable Instruments
Jack Horsby



5 Bedside Cart Systems
Jon Cooke



6 Kinematics & Control
Johnathan Hung

The last element of intelligent system architecture is the technologies selected and how they are integrated. Integration, done well, leverages technology capability, availability and compatibility from a broad range of industries and disciplines

— a process that takes multidisciplinary, multi-industry expertise. The challenge, for many companies, lies in accessing this pool of knowledge and experience to bring all these things together. For a smaller company, funding may not support a larger, multidisciplinary team, and for a large strategic organization, silos are often a barrier to cross-functional pollination.

To address this, teams can adopt two main practical strategies.

1. Technology landscaping: Systematic exploration of relevant technologies, before committing to architecture decisions. By casting the net wider than the obvious and involving expertise from adjacent industries and technologies, teams can identify solutions and innovations from adjacent industries that may offer performance or cost advantages. It provides a much larger pool of ideas to pull from and qualifies these against the experience of seasoned experts.
2. Leveraging third-party subject matter experts to augment internal capabilities: Partnerships with specialists in areas such as advanced sensing, novel materials, or niche manufacturing techniques allow teams to access deep expertise without permanently expanding headcount. This flexible model enables teams to scale knowledge as needed, ensuring that each subsystem has the necessary breadth and depth of thinking behind it.

Conclusion

In a space like surgical robotics, where expectations of performance are constantly advancing while form factor is limited by the physical constraints of hospitals, functional density is critical to competitiveness. The teams that succeed will be those that accurately understand the user's needs and resist the temptation to over-engineer and instead anchor every architectural decision in clinical value, system-level thinking, and a clear understanding of technological trade-offs.

At Cambridge Design Partnership we've been supporting our partners' surgical robotics development teams with exactly this. Our teams deliver system architectures that prioritize clinical impact and create robust foundations for progression into engineering design and industrialization.

It's an exciting time to be in this space, and we're proud to be supporting and accelerating the next generation of surgical robotics. Get in touch to find out more.

Cambridge Design Partnership's Surgical Robotics team works with clients to develop innovative, high-impact devices. Reach out today, and a member of our Surgical Robotics team will get in touch.

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Bring innovative surgical robotics to life with speed and clarity.

Cambridge Design Partnership partners with leading surgical robotics innovators to provide in-depth, expert support across every stage of product development. We work to find the right path forward as quickly as possible to ensure speed-to-market and commercial viability.

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