The Design Space of Livestreaming Equipment Setups: Tradeoffs, Challenges, and Opportunities

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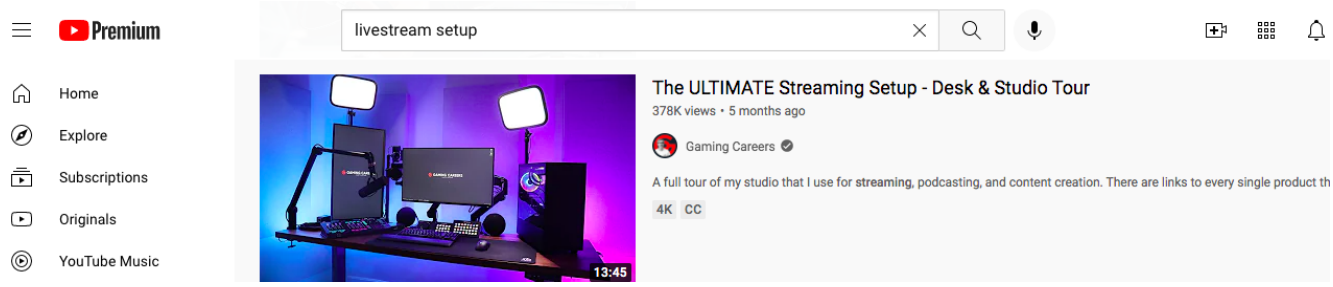

Figure 1: Example of a livestream setup video on YouTube. In this paper we survey the landscape of livestreaming setups.

ABSTRACT

Livestreaming has grown popular in recent years, with millions of people broadcasting themselves making digital art, playing games, programming, and doing other activities on sites like Twitch and YouTube. While many researchers have studied the actions of both streamers and their viewers, to our knowledge there has been no comprehensive analysis of the actual hardware and software equipment used in livestreaming. In this survey paper we present a holistic overview of modern livestreaming equipment in 2022 by analyzing 40 videos where streamers talk about various aspects of their setups. We categorized their equipment choices into a design space with ten dimensions: computer, software, stream control, encoding, cameras, lighting, video accessories, microphones, audio mixers, and audio accessories. We found that each streamer must make tradeoffs between lower- and higher-fidelity options within each dimension. Our design space analysis can inform ideas for future streaming support tools and, more broadly, tools for remote collaboration and learning via live video. As more of us work and learn online, we are in essence becoming amateur livestreamers, so understanding how professional streamers use their equipment to effectively engage their audiences might help us also engage better with our coworkers and classmates.

CCS CONCEPTS

• **Human-centered computing → Human computer interaction (HCI)**.

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1 INTRODUCTION

Millions of people now use platforms like Twitch and YouTube to broadcast themselves live as they are playing games [34, 44, 47, 53, 55], making digital art [23], programming [2, 9, 20, 21], and doing other activities. Since these people are acting as *single-person live video production crews*, a big challenge for aspiring livestreamers is figuring out what sorts of equipment they need in order to produce a compelling stream given their budget constraints. Some streamers give their personal tips by making 'livestream setup tour' videos (see Figure 1). However, these walkthroughs each cover only a limited set of options so it is hard for novices to understand the full range of equipment possibilities.

To provide a broad overview of the current state of practice, we present (to our knowledge) the first comprehensive survey of livestreaming equipment setups. We performed a content analysis of 40 livestreaming setup walkthrough and tutorial videos (e.g., Figure 1) to characterize the types of hardware and software that streamers recommend and the design tradeoffs of each. We synthesized these findings into a *design space of livestreaming equipment* that captures the main dimensions of variation in streamers' setups. Figure 2 shows our design space, which contains ten dimensions arranged into three groups: broadcasting, video, and audio equipment. Each streamer can choose options within each dimension according to fidelity, which usually correlates with monetary cost. For instance, they can repurpose (re-use) an old computer as their

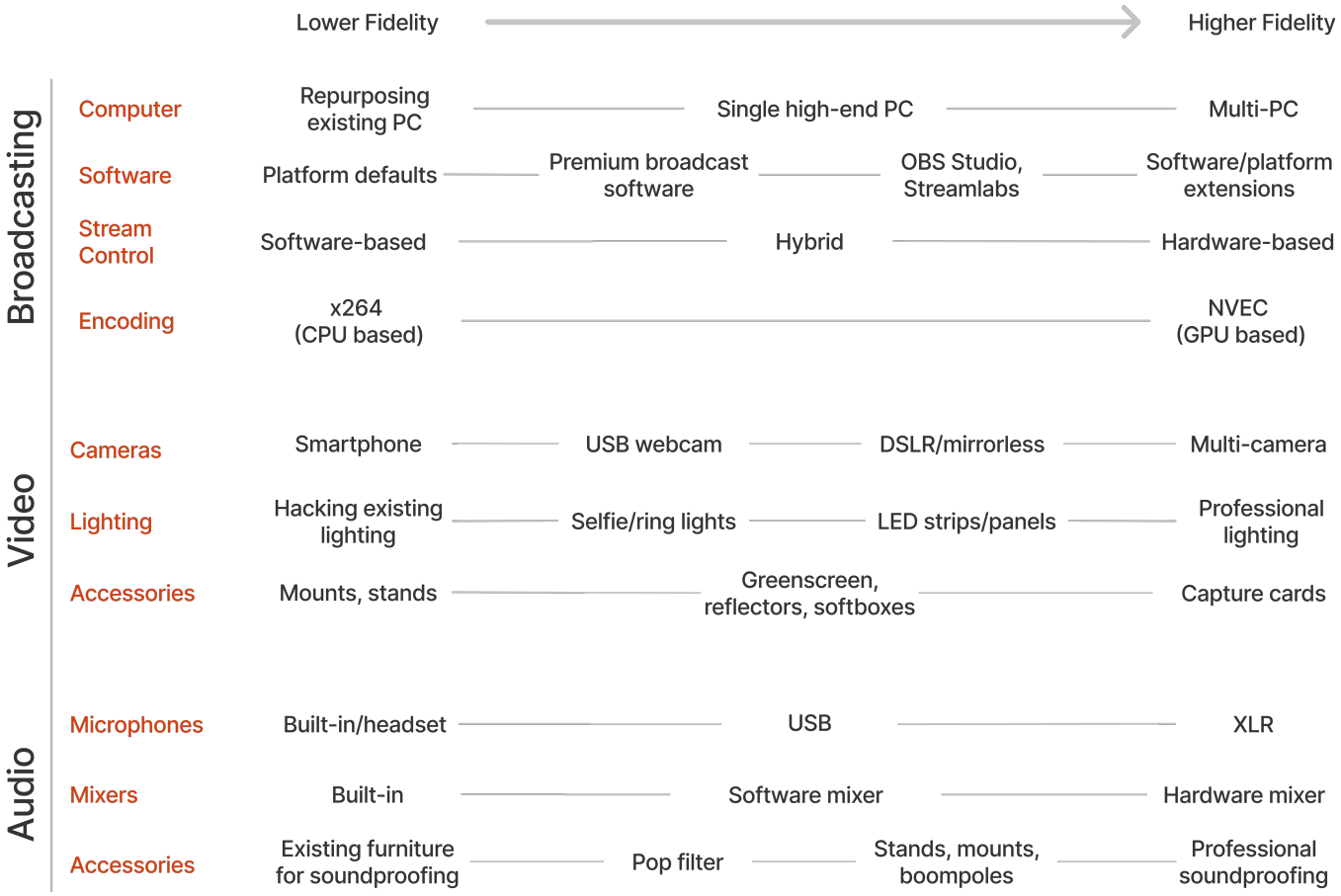

Figure 2: We analyzed 40 streaming setup videos to synthesize a design space of livestreaming equipment. Our design space captures ten dimensions of variation in equipment choices. Each dimension offers common options along a spectrum from low- to high-fidelity.

streaming PC, build a single high-end PC, or build an expensive multi-PC setup.

Throughout this analysis we discovered common challenges that streamers face in integrating separate components together into a unified setup, managing the logistical complexity of equipment while broadcasting in real-time, and making decisions about how to incrementally upgrade equipment without getting overwhelmed. We propose ideas for future tools that can help streamers manage technical logistics so that they can focus on the actual craft of livestreaming.

Our findings contribute to the growing body of research on livestreaming, which complements prior studies that have so far focused on either streamers or their viewers (see Section 2); in contrast, our study is the first to focus on analyzing the actual equipment used to stream, which has implications for technical systems design and integration.

More broadly, our findings have implications beyond livestreaming since the global COVID-19 pandemic has forced millions of people to work and learn remotely via live video. In essence, many of us are now amateur livestreamers as we hold more classes and work-related meetings via videoconferencing. The lessons we learn from popular modern-day streamers can potentially inform the future of remote collaboration and learning tools.

In sum, the contributions of this paper are:

- A design space of livestreaming equipment, derived from content analysis of 40 streaming setup/tutorial videos.
- A discussion of challenges that streamers face when integrating, managing, and upgrading their equipment.

2 RELATED WORK

Our design space analysis extends three existing lines of research: 1) studies of livestreamers and their viewers, 2) HCI systems to support livestreaming, 3) survey papers that formulate design spaces.

2.1 Studies of Livestreamers and Their Viewers

Over the past decade as livestreaming platforms have grown in popularity, many researchers have studied the activities of both streamers and their viewers. We found that these studies fall into four main clusters, which each inspired our study in different ways:

1) Some focus on one specific domain that is popular amongst livestreamers, usually conducting surveys or interviews with both streamers and viewers in that domain. Popular domains of study include computer gaming [34, 44, 47, 53, 55], digital art [23], computer programming [2, 9, 20, 21], online education [8, 10, 13, 21, 26], and IRL (In Real Life – e.g., walking around) mobile streams [57] to showcase outdoors scenery [37] and preserve cultural heritage [36]. We were motivated by this prior work to include several popular streaming domains in our video content analysis, most notably gaming, digital art, and programming. However, mobile and IRL streams are out of scope for our study since we chose to focus on desktop equipment setups.

2) Some studies zoom in on the experiences of specific demographics of streamers, such as lifestyle streamers in China [41], those who use virtual 2D or 3D avatars instead of their faces (i.e., VTubers) [40], and streamers with visual impairments [29]. These mentioned aspects of streaming equipment within the context of streamers' overall experiences. For instance, Jun et al. reported on equipment challenges faced by streamers with visual impairments [29], such as interfacing between streaming software, screen readers, and text-to-speech apps, along with accessibility concerns with certain streaming software. Lu et al.'s study of VTubers found that widely-available software for controlling 2D avatar animations limited their expressiveness and that more professional streamers could afford full-body motion capture equipment that made their 3D avatars more expressive [40]. In contrast, our study zooms out to categorize more general-purpose streaming equipment such as computers, cameras, and microphones.

3) Researchers have also studied the motivations of livestream viewers [28, 54], how they support streamers both emotionally and financially [67], and emotional reactions to co-watching streams together with a large audience [42]. Our study is inspired by some of their findings about the critical importance of streamers engaging with their audience live; what makes livestreaming unique is that it is more than simply recording pre-made videos. Thus, streamers need to adopt a set of equipment (constrained by their personal budget) that allows them to quickly switch scenes, interact with the chat, and show their real-time facial reactions to make viewers feel engaged.

4) Since livestreaming offers the possibility of streamer-viewer interactions, researchers have studied these dynamics of real-time performance [27, 33] as well as how monetary incentives (e.g., cash tips and digital gifts sent by viewers) affect streamer behavior [62]. Also, since viewers can interact with streamers via text chat, researchers have studied how volunteer moderators manage these chat channels to mitigate abuse and harassment [3, 6, 66]. Some studies mention streaming software extensions for moderating the chat, managing donations, and displaying on-screen notifications to enhance streamer-viewer interactions. These tools inspired us to add a *software/platform extensions* category to Section 4.1.2.

Our paper follows this lineage of livestreaming studies, but instead of focusing on streamers and their viewers like prior work has done, we turn our attention to the actual equipment that streamers use in practice. Prior work has mostly focused on motivations and challenges faced by streamers (and viewers) with regard to the actual topics they are streaming (although some touch upon specific aspects of equipment, as mentioned above). In contrast, our work instead focuses on streamers' relationships with the hardware and software equipment they use. To our knowledge, our study is the first to formulate a design space of the current state of desktop livestreaming equipment setups.

2.2 HCI Systems to Support Livestreaming

Besides studying the current practices of streamers and viewers, HCI researchers have also built new interactive systems to enhance the livestreaming experience.

One major category of systems research involves enhancing the text chat communication channel between streamers and viewers. For instance, Chen et al. [7] augmented text chat with audio, video, and image stickers. Helpstone extends the chat features of the Hearthstone game to make it easier for stream viewers to give in-game hints and feedback [32]. Snapstream enables viewers to take, annotate, and post screenshots to the chat stream [68]. VisPoll allows a group of viewers to directly make visual inputs atop the video stream [11]. Similarly, StreamSketch lets streamers and viewers of art streams interact via a mix of sketching and text annotations [39].

Another category of systems aims to summarize the contents of streams to reduce information overload. For instance, Fraser et al. developed algorithms to split livestreams of people using creative tools (e.g., image editors) into meaningful segments that can be used to create shorter clips or tables of contents [22]. Kobs et al. fine-tuned sentiment analysis for stream text chats, which can help streamers feel more engaged with real-time audience reactions [30]. StreamWiki enables viewers to collaboratively summarize livestream contents for longer-term archiving. [38].

Finally, recent systems extend livestreaming beyond desktop and mobile settings. One representative example here is XRStudio, a platform for building lecture livestream experiences for instructors and students within virtual reality [45].

Our work differs from these systems projects because we aim to survey the *current state of practice of what livestreamers use in-the-wild*. These aforementioned papers describe novel research prototypes that have not been turned into widely-used products; thus, we did not include them into our design space analysis (Figure 2) since we did not observe streamers using them in the 40 videos we analyzed (Table 1). One area for future work is to create a combined design space with both research prototypes from academic papers and tools that are used by practitioners.

2.3 HCI Surveys that Formulate Design Spaces

Methodologically, our work is most closely-related to HCI survey papers [65] that formulate a *design space* to capture different dimensions of variation in technical system features [31].

Traditional survey papers perform a systematic literature review to map out the landscape of academic work in a subfield. For instance, Brudy et al. reviewed 510 papers to formulate a comprehensive design space of multi-device interactions [4], with dimensions such as scale, temporal synchronicity, and user relationships. Frich et al. categorized 143 papers into a design space of creativity support tools [24], with dimensions such as device, phase of creativity process, and target user group. Pfeil et al. reviewed 52 papers to synthesize a design space of remote telepresence systems [48], with

dimensions such as camera type, camera placement, and viewer communication.

Some HCI survey papers also analyze widely-used software tools, blog posts, product websites, and other popular media in order to capture systems used outside of academia. For instance, Lau et al. categorized 16 academic papers, 29 industry product websites, and 15 open-source software projects into a design space of computational notebook tools [31] with 12 dimensions, including data source, execution order, and versioning granularity. Similarly, Terrenghi et al. analyzed a few dozen academic papers and commercial products (e.g., touchscreen kiosk monitors) to formulate a design space of interactive display technology [58], with dimensions such as size, interaction modalities, and types of supported social interactions. Segel and Heer analyzed the content of 58 interactive visual storytelling webpages (e.g., New York Times interactive articles) to formulate a design space of narrative visualizations [52] consisting of 7 dimensions, including transition types, ordering, and highlighting. Striner et al. analyzed design process documents produced in a university gaming course to formulate a design space of audience participation needs for Twitch gaming livestreams [56], with dimensions such as agency, pacing, and community.

Our paper follows in this tradition of practitioner-oriented design space analyses since we analyzed 40 streamer-made videos and the websites of products mentioned in those videos to formulate a design space of livestreaming equipment setups. We chose this approach (detailed in Section 3) since we wanted to map the state of current practice in the field rather than surveying academic papers (though Section 2.2 gives an overview of relevant HCI systems research).

3 METHODS

We surveyed the current state of practice in terms of the kinds of hardware and software equipment that livestreamers use. Since streamers are most adept at expressing themselves via video, we found that searching for information online about their setups yielded mostly video results (rather than, say, blog posts). We noticed that popular streamers like to post "walkthrough of my livestreaming setup" types of videos to engage with their fans who are curious about what equipment they use. Many videos we collected for our design space analysis came from this genre (see Table 1).

3.1 Data Collection Methodology

To find these kinds of livestreaming equipment videos we searched YouTube in Jan–Feb 2022 for terms such as 'livestream setup', 'livestreaming guide', 'how to livestream', 'livestream software recommendations', and 'livestreaming setup comparisons' to look for videos where streamers either walked through their setups or gave step-by-step tutorials about how to set up specific equipment. (Note that although many people stream on Twitch, in our experience they also have a personal YouTube channel they use to upload walkthrough or how-to videos about their technical setups.)

Each of our YouTube searches yielded dozens or more results (YouTube currently does not show the exact number since it produces additional results dynamically as users scroll down the page in an 'infinite scroll' UX pattern). Anecdotally we noticed that the first 10–15 results for each search were the most relevant. We used additional heuristics such as number of video views to filter, although those were often correlated with search ranking. We also eliminated videos that were advertisements or reviews for a specific product, since we wanted to find naturalistic videos of streamers describing their actual setups. Critically, we strove to sample a diverse variety of video types covering: 1) different domains of streaming (e.g., art, gaming, programming), 2) varying budget levels (from low-budget to more expensive setups), 3) those made by both popular 'celebrity' streamers along with less well-known streamers (e.g., an amateur musician from Singapore or someone who set up a small church livestream), 4) varying breadth of coverage (e.g., focusing on using one piece of hardware in-depth versus a general tour of the streamer's entire room setup), 5) different genres ranging from step-by-step tutorials to more casual walkthroughs of a streamer's home studio.

3.2 Data Overview and Analysis

We watched each video to perform a media content analysis, which is a standard qualitative research technique in fields such as communications and media studies [43]. This method involves treating the media itself as the primary subject of study. In particular, we noted how each streamer described their setup, what hardware and software components they mentioned, and what design tradeoffs and challenges they brought up (e.g., pros and cons, alternatives they considered using, etc). When they mentioned specific pieces of hardware or software, we went to the official product websites and looked at its technical documentation when available. Some streamers also linked to supplemental websites in their video descriptions, which we also read.

We used a combination of deductive and inductive techniques to guide our analysis. Specifically, we set out to formulate a design space[1] out of our observations of livestreaming setups. We were inspired by the methodology of Segel and Heer [52], who formulated a design space of narrative visualizations by doing media content analysis of 58 interactive news webpages, and Lau et al's design space of computational notebooks [31]. Although we started with this high-level goal, we came up with the specific dimensions of the design space via an inductive process [12] where the research team watched each video individually, met multiple times to merge our analysis notes, and categorized them together into themes. We made several iterations as a team before finalizing our 10 dimensions and representative examples within each one (see Figure 2). We split or merged themes as necessary to aim for a parsimonious summary, while acknowledging that there will be ambiguities present. For instance, many types of hardware may count as 'accessories' but we put some into more specific themes like stream control or lighting.

We decided to stop after 40 videos since we felt we had reached a reasonable qualitative saturation point [51]: the same themes in our design space kept re-appearing in subsequent videos we watched, and it became harder to discover uniquely new themes.

[1] In HCI research, a *design space* succinctly captures multiple dimensions of variation in possible system features within a given domain [31]. See Section 2.3 for prior research on formulating design spaces. In our case, each livestreamer's setup covers a specific range in the design space we developed.

Table 1: The livestreaming setup and tutorial videos used in our qualitative content analysis. 'yt=' is the video's YouTube ID.

ID	Length	Summary of contents
V01	13:44	Tour of a gaming streamer and content creator's high-fidelity streaming setup (yt=UrZZoDw9Yfg)
V02	07:24	Budget-focused streaming setup with ideas for repurposing existing furniture and tools (yt=L6ZJaKqALgM)
V03	11:08	Walkthrough of streaming setup for a software engineering content creator (yt=3Zd9c-cZ5eE)
V04	13:32	Tutorial for how to stream on a gaming PC with a larger budget (yt=xcVSxchn0uM)
V05	04:42	Setting up audio for game streaming and the equipment recommended to do so (yt=zRw1FZPrQao)
V06	18:00	Streamlabs software setup tutorial for beginner streamers (yt=pY6nhTzc85s)
V07	18:46	Building a PC streaming setup and information about video encoders (yt=Ai3nnhSIXec)
V08	20:02	Walkthrough of a PC gaming and streaming setup (yt=pvdtUSde3nw)
V09	08:24	Hardware accessories that are useful for livestreaming (yt=Y02wZGfO6Vk)
V10	04:49	Quick video about getting a stream working using OBS Studio (yt=wt-ac45JQaU)
V11	17:16	Installing a streaming setup with soundproofing in a new house (yt=ED6DWfpaGIk)
V12	10:10	Guide for setting up and using a Stream Deck [16] controller hardware (yt=MQxmuwuHJo0)
V13	14:55	Educational tech streamer going over their gear and discussing alternatives (yt=N173ajQi3X4)
V14	23:23	Guide for setting up and configuring a dual-PC stream (yt=ajSxWGCDgqM)
V15	12:04	Showing a wide range of livestreaming equipment from beginner to pro level (yt=niP7l_F5pOU)
V16	12:10	Streaming setup tour before the streamer moves to a new studio (yt=_quSTWJx-OU)
V17	18:27	Showing off the pros and cons of using a video switcher interface for streaming (yt=KoZwgvudhSM)
V18	21:04	How to set up a livestream for churches who want to stream their services (yt=-av6jyKma3c)
V19	31:00	Iterative setup of a dual-PC streaming setup and troubleshooting common issues (yt=3gGpiTrkZzw)
V20	23:15	Tutorial showing how to use 20 different features of OBS Studio (yt=zXRNPozVRZg)
V21	11:26	Setting up a dual-PC streaming setup and configuring software to support it (yt=47ZJWFHZuV0)
V22	28:59	Comparing several video switcher options for livestreaming (yt=UjFqwu3Gumo)
V23	08:22	A budget-oriented audio/video setup with tips for maximizing quality at low cost (yt=_3ZW4MAhM2w)
V24	21:27	Setting up and using OBS and its features for brand-new streamers (yt=EuSUPpoi0Vs)
V25	06:42	Livestream setup for musicians wanting to stream during the pandemic (yt=2b6_iDBU2wg)
V26	07:00	Configuring a multi-camera livestream setup using OBS (yt=8UtXvJq-l5M)
V27	10:42	Budget livestream setup for under $500 USD (yt=qMgWYem6O2U)
V28	06:43	Choosing audio and camera options for a livestream or videoconferencing setup (yt=9EXdlHv8VXM)
V29	16:41	Tips for improving a stream on low-budget PC equipment (yt=T8gJWDaWcU8)
V30	18:05	Livestream setup tour for two sisters who stream together (yt=csYP54xZupI)
V31	14:33	High-budget streaming setup tour and showcase (yt=Tdo9iY5Lyx8)
V32	14:51	Guide for making even budget microphones sound good while streaming (yt=C6QPS3DlYKI)
V33	07:37	Creating a streaming setup with only a laptop (yt=hEUJQ4Q8SHg)
V34	06:56	Artist-focused livestreaming setup tutorial (yt=4WVHQwqxn7Q)
V35	09:11	Soundproofing choices and how some premium solutions aren't worth it (yt=VuTi4ntMA8Y)
V36	12:25	OBS tutorial and guide for setting up a USB webcam microphone (yt=DZnkyq4kqkE)
V37	06:12	Setting up a multi-camera livestream and configuring software to support it (yt=2iuk8txffrw)
V38	14:59	$1200 budget streaming setup including PC and peripherals (yt=7xggjnvT_Ok)
V39	16:32	Comparison of the top streaming software available for macOS (yt=6FIBZqFVv7I)
V40	08:42	Tutorial for setting up OBS to stream in 1080p (yt=muwqdMQptKo)

To double-check that we did not miss any major themes by relying solely on videos, we also searched Google for blog and forum posts that described streamer setups. The few that we read through covered similar sorts of information as the videos in Table 1, although they tended to be less detailed.

We formatted our design space diagram to match Lau et al's design space of computational notebook systems [31], with variations within each dimension plotted from left to right to represent lower to higher-fidelity, respectively. Although there is no universally agreed-upon definition of fidelity, we use the following operational definitions: A *low-fidelity* equipment option is usually simpler, easier to set up, and more novice-friendly, but it lacks customization features that professionals want. A *high-fidelity* option tends to have a higher barrier to entry and is not as novice-friendly, but it has more customization options that can be used to achieve professional-grade performance on factors such as processing speed or audio/video quality. Fidelity is correlated with monetary cost, but not in all cases: For instance, OBS Studio [1] is free and open-source software but can be configured to produce high-fidelity livestreams.

3.3 Study Scope and Limitations

Our design space analysis focuses on individual *desktop-based* livestreaming where a single streamer broadcasts from a static fixed location such as a room in their home or office. This is the most common setup for streaming on sites such as Twitch and YouTube, and it is what is studied by most prior research in Section 2.1. Note that this scope means our design space does *not* encapsulate the range of mobile and IRL (In Real Life) setups where, say, someone walks around a city streaming from their smartphone camera [37, 57] (e.g., on Instagram Live). It also means that we do not cover equipment that is meant to be operated by a production team of staff that coordinates alongside the streamer, as would be the case for more professional venues like live television shows or Esports (video gaming) tournaments in a stadium.

Our video corpus came only from YouTube, so we might be missing insights posted to venues such as blogs, forums, or other video platforms. In our experience, YouTube is now a standard place for streamers to upload their setup videos, and we strove to sample a diverse variety of such videos (Section 3.1). For instance, even many Twitch streamers upload clips to YouTube since it is harder to archive and search through videos on Twitch. That said, some might post relevant short-form impromptu thoughts to TikTok, so that can be an emerging domain to explore in future work.

Also, our design space is derived solely from media content analysis [43] of 40 videos, but we did not directly survey or interview streamers. We used what streamers talked about in these videos as our primary data sources, but those verbal descriptions could be incomplete. There can also be selection bias in our corpus of 40 videos due to our particular search terms. To address this limitation, in future work we could show our design space and representative examples to streamers to get their direct feedback and see what elements they would add or remove.

4 THE DESIGN SPACE OF LIVESTREAMING EQUIPMENT

This section presents the results of our design space analysis, which we summarized in Figure 2. We report on general trends that we observed across multiple videos in Table 1. When relevant, we report direct quotes spoken by streamers within specific videos, labeled by their video ID.

4.1 Broadcasting

Our first group of design space dimensions relates to the live broadcasting portion of a streamer's production, which includes software that captures their computer screen, as well as all of their audio, video, and other multimedia sources. This software then organizes these into 'scenes' that they broadcast through a platform such as Twitch.

For example, in Figure 3 we see a streamer who is using the popular open-source tool OBS (Open Broadcaster Software) [1] to configure an artistic overlay image and his camera for an 'intermission' scene, where he can sit and interact with viewers during breaks in between streaming his gameplay content.

This group has four dimensions (see Figure 2), which we discuss in the following subsections. For each dimension we present commonly-suggested options ordered from low to high fidelity.

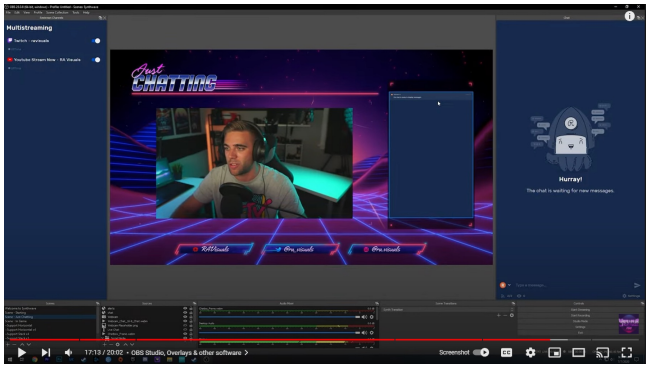

Figure 3: A streamer uses the popular OBS Studio[1] broadcasting software to configure visual scenes, transitions, audio, video, and other extensions to broadcast live on Twitch.

4.1.1 Computer. Streamers suggested three options for the personal computer (PC) they use to broadcast their streams:

Repurposing existing PC: The lowest-cost option is to take an existing PC and repurpose it as a streaming PC by installing broadcasting software and connecting it to all of the acquired streaming equipment like cameras and microphones. Many streamers started out here, as it is an affordable method to dip their toes into streaming. However, the resource-intensive nature of streaming can lead to performance degradation, especially for streams with graphical overlays and animations, running intensive applications like computer games, or broadcasting high-quality audio and video. Some of the tutorial videos in our analysis touched on different ways to support budget or repurposed PCs, which involve lowering the quality of stream output and using streaming software configurations to relieve the strain on a lower-end PC (V18, V23, V27, V29, V38) until one manages to upgrade to a high-end PC or multi-PC setup.

Single high-end PC: Instead of using an existing PC, which was probably not designed for streaming, many streamers recommend custom-building a high-end PC. Due to the resource-intensive nature of both running the actual applications to stream (e.g., a modern 3-D game) and the broadcasting software along with video and audio feeds, these PCs usually require higher specifications than normal ones and can reach costs of $2000-5000+ USD.

Multi-PC: Professional streamers often use a second purpose-built high-end PC that is dedicated to handling the streaming broadcast, while their main PC runs only the applications necessary for accomplishing their intended task (e.g., creating art, playing a game, programming). Enabling streaming from a multi-PC setup requires extra hardware like capture cards to feed the main PC's live video signal into the streaming one (see Section 4.2.3), which increases the complexity and cost of the final setup. For example, depending on the desired quality (e.g., 1080p vs 4k resolution) and whether high-resolution cameras are attached, this setup may require more expensive hardware, which can raise computer-related costs to up to $10000 USD.

4.1.2 Software. Having chosen a computer setup, a streamer must then pick what broadcasting software they want to use. This software captures their desktop screen, running applications, audio,

video, and other multimedia sources, then organizes these components into 'scenes' that they broadcast live to a platform such as Twitch or YouTube.

Platform defaults: Platforms like Twitch and YouTube provide their own default free software that makes it easy for newcomers to quickly start streaming. However, these are the lowest-fidelity since they lack many features found in higher-fidelity choices like OBS (e.g., support for capture cards), so streamers looking to customize their stream will not use these. Free defaults are also tied to each platform, so switching platforms or multi-streaming (streaming on multiple platforms at a time) is not possible. As a result, streamers in our videos rarely mentioned this option.

Premium broadcast software: Several streamers (V13, V18, V31, V39) talked about premium broadcast software like Ecamm Live [14] and VMix [35] that, for some cost ($15-50 USD per month or $50-1200 for a single license [17]), provide features that are not available on the free platform defaults. For instance, V39 mentioned:

> "They also make it so easy just to move and adjust stuff on the fly while you're live. So if you wanna zoom in on a screenshare so that your viewers can really see what it is you're showing them, you literally just pinch to zoom on your trackpad and it's gonna zoom in on that screenshare."

Some also include filters and effects that change the live video and audio, and multi-casting to different platforms.

OBS Studio, Streamlabs: By far the most widely-used option amongst streamers in our analyzed videos was OBS (Open Broadcaster Software) Studio [1] and software that extends OBS, such as Streamlabs [50]. OBS is open-source and free, but forks like Streamlabs do have subscription fees ($20 per month) that provide other features like overlays and multi-streaming support. Despite being free[2], OBS Studio can result in higher-fidelity streams than the above category of premium software since it is designed as a power tool for advanced users. However, the downside of OBS's flexibility is that it is harder to set up. For instance, V39 mentioned how OBS has a steep learning curve: "Simple things like not having any templates, or presets for different livestream qualities, or the different platforms just means that you actually need to know what you're doing or go and find out what the correct settings are to get the best results."

Software/platform extensions: For even greater fidelity, streamers can install extensions and plug-ins to their broadcasting software to customize stream appearance and functionality (e.g., adding viewer donation alerts). Some extensions are offered by streaming platforms like Twitch [60, 61] (e.g., a Twitch extension for tracking the streamer's eyes [19]), while others control broadcasting software remotely (e.g., OBS-websocket [46] can switch OBS scenes remotely or have viewer donations automatically trigger visual/audio effects).

4.1.3 Stream Control. While they are broadcasting live, streamers need ways to control the appearance of their stream and adjust it in real-time. Broadcasting software (see prior section) come with some built-in controls, but advanced streamers prefer dedicated hardware to control their streams rather than relying solely on their mouse and keyboard.

[2]Higher-fidelity usually means higher monetary cost, but for software there are free options that can result in higher-fidelity outputs than paid ones.

Figure 4: The Elgato Stream Deck [16] is an example of a hybrid stream control interface. It contains programmable buttons (with customizable mini-LED displays on them) to control streaming software like OBS using macros that the streamer specifies.

Software-based: Software like OBS lets streamers activate different scenes on-the-fly, like an 'intermission scene' that has their facecam (camera pointed at their face) made to fill up most of the screen or a 'gaming scene' where the facecam is made smaller to fit in the corner overlaid onto the game being played full-screen. This is the least convenient option, though, since it requires the streamer to move away from what they are focused on doing on-screen (e.g., playing a game) to navigate separate menus in the broadcasting software or to use a separate set of keyboard shortcuts.

Hybrid: This approach involves using hardware input devices to control the broadcasting software (i.e., a hybrid of hardware and software). Such input devices include foot pedals ($15-90 USD) and the popular Elgato Stream Deck. The Stream Deck ($90-250 USD), shown in Figure 4, contains hardware buttons that streamers can bind to custom macros. Once set up, when they press these buttons it performs various stream functions like changing scenes, muting microphone or music, skipping donation messages, and anything else that broadcasting software and extensions afford. Each individual LED button on the Stream Deck can also present a customized image and text so the streamer knows what each button does. V03 said that it "feels like I have my own mission control, which adds sort of a fun dimension to streaming." Streamers have found these types of devices to be incredibly useful as "pretty much every task that I'm doing day-to-day as a content creator has some functionality control through one of these stream decks." (V01)

Hardware-based: On the highest end of fidelity, there are purely hardware-based solutions for stream control called *video switchers* (Figure 5). These can provide scenes, transitions, features like picture-in-picture, auto-camera selection, audio mixing/levels, and more in a single hardware solution without needing to interface with broadcasting software on the streamer's PC. Thus, these devices are seen as more reliable than software solutions, especially for more complex setups that involve multiple video and audio inputs. These are more likely to be used for larger productions such

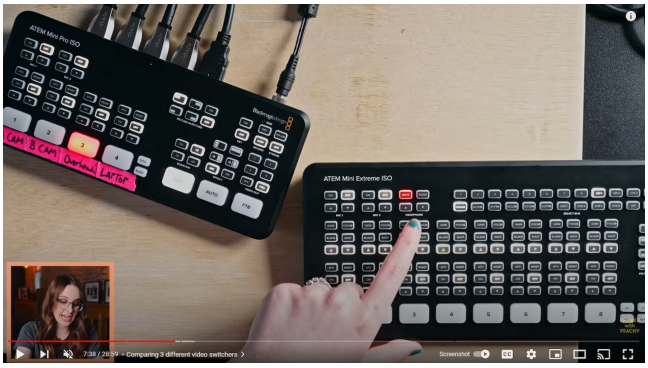

Figure 5: This streamer uses a hardware video switcher to customize scene composition (e.g., picture-in-picture) and transition between scenes in her stream. Doing so in hardware takes the processing load off her computer and can thus be faster and more reliable.

Figure 6: A DSLR camera configured to be used as a high-fidelity facecam (face camera), mounted above the streamer's main monitor.

as V17 and V18 (e.g., conferences, podcasting, or church streams), come with a much higher price tag ($600-5000 USD), and thus are less accessible than hybrid solutions like the Stream Deck.

4.1.4 Encoding. Finally, streamers weighed the pros and cons of the two main video encoding methods for livestreams. The lower-fidelity option is x264 CPU-based encoding, which is for lower-budget streams. However, the preferred solution was NVEC GPU-based encoding, which requires an expensive Nvidia video card ($250-2500+) but can handle higher quality streaming. Some also mentioned that due to recent GPU chip supply shortages [59], it may be harder for people to obtain NVEC-capable hardware for streaming, so x264 with a higher-end PC may also be adequate.

4.2 Video

The next group of design space dimensions relates to hardware to provide a live video feed of the streamer and their physical environment (e.g., their room), which can increase personal engagement with viewers above and beyond providing just a screenshare of their computer (e.g., showing a live game or image editing program). V07 said that while it is possible to stream without a camera (and several popular streamers do), "In my personal opinion it really disconnects the viewing experience between you and your viewer if you don't show your face on stream."

Here are the three video dimensions that streamers mentioned:

4.2.1 Cameras. Streamers must first choose a camera to broadcast their face to show live reactions, real-space physical work (e.g., drawing, painting, playing musical instruments), or to interact with viewers.

Smartphone: While most streamers recommend at least a USB webcam, some showed how to repurpose an existing smartphone into a camera that rivals most webcams. But wear-and-tear on the device might make this a temporary solution until one can invest in a dedicated camera. The setup of a smartphone as a streaming camera also requires installing a mobile app to broadcast video output onto the web that streaming software can add as a source, and it may also become tedious to constantly mount and unmount it from a fixed stand near the computer.

USB webcam: These are easy to set up since they connect to the computer without extra hardware that a DSLR/mirrorless camera needs (see below for details). Webcams usually come with a built-in microphone, but most of the streamers who used webcams do not recommend relying on it (see Section 4.3.1 for microphone choices). V13 also noted that high-intensity lighting can also wash out the image of most webcams, so care must be taken when using one.

DSLR/mirrorless: As a high-fidelity option, streamers recommend DSLR or mirrorless cameras used by photographers (Figure 6). These provide advanced features like sharp autofocus when the streamer moves around, depth-of-field to blur their background, and changing ISO (photo sensor sensitivity) or white-balance. However, these can be expensive for streamers just starting out ($1000-$3000+ USD), so the general recommendation is to get a webcam first and then upgrade later. Also, these cameras must either be connected to a hardware video interface (see Section 4.1.3) or to a PC via a capture card; both options increase cost and setup complexity.

Multi-camera: This highest-fidelity option gives viewers multiple live views into the streamer's physical environment (Figure 7). While one camera may be the main facecam, other cameras can provide overhead shots of a drawing tablet, musical instrument, or other device the streamer is using, as well as wide shots or other views the streamer might want to share. A multi-cam setup introduces complexity in terms of stream control, which may lead to needing a video switcher (Section 4.1.3) or several capture cards and a powerful enough computer to manage all the video sources. V13 mentioned the importance of coupling high-end cameras with dedicated video switcher hardware: "Having a physical hardware solution can make it a little easier so it's not absolutely critical but in my case it simplifies matters greatly because now I can have up to four different cameras with a single device."

4.2.2 Lighting. Streamers mentioned that lighting is "the secret to a good-looking stream" (V04) but novices may overlook it. For example, novices who use only their monitor to light their face can appear jarring to viewers as dark scenes in games will make it

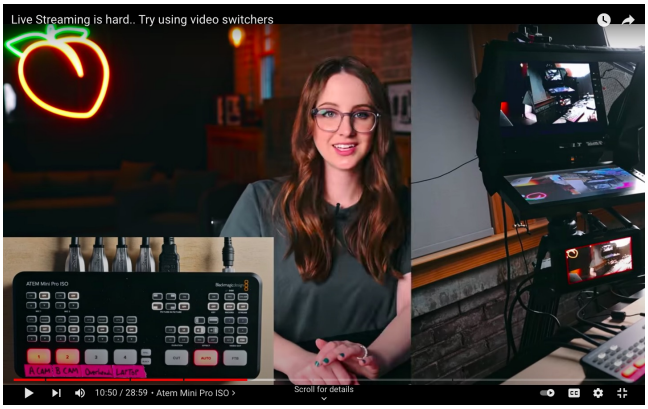

Figure 7: A tech review streamer uses a multi-camera setup controlled by a hardware video switcher to broadcast 3 camera angles.

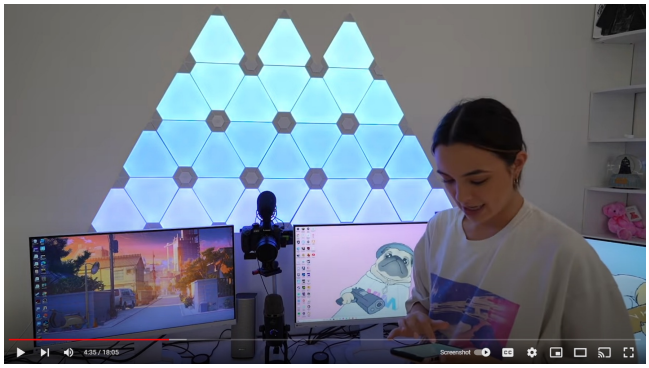

Figure 8: Example of using multiple wall-mounted LED panel lights as a key light (main source of light) to illuminate the streamer while she is on camera. These lights can be programmatically controlled via a mobile app.

hard to see their face and a sudden brightness change on-screen can overexpose the video.

Hacking existing lighting: Lighting can get expensive, so some budget-minded streamers gave advice on how to repurpose (hack) existing lighting in one's home to mimic a higher-end setup for almost no cost. For example, instead of purchasing light boxes, which can be expensive and require a large amount of space to rig up, use an old lamp with a halogen bulb, which can get consistent and true-to-life colors out of the camera. Then add partially-transparent paper (e.g., wax paper) to diffuse the light, or even just bounce the light off the wall to soften its glow.

Selfie/ring lights: Some streamers aiming for budget setups used selfie lights (ring-shaped LED lights that a camera can sit in the middle of) as their *key light* (main source of light). These are relatively cheap ($20-100 USD) compared to professional lighting rigs while still providing decent light for the streamer to show their face on-screen.

LED strips/panels: These are generally used for background, fill, and ambient lighting and allow the streamer to add color and personality to their stream. For instance, V13 mentioned how LED panels add a "little splash of color up on the background to create some depth and separation of me from the background." Several also showed how to use LED panel lights as their main key light, which can save money over buying professional key lights (see Figure 8).

Professional lighting: Some streamers recommended expensive lighting setups to make videos look professionally-produced. These setups are similar to what photographers use and can run over $1000+ USD.

4.2.3 Accessories. Finally, accessories can increase production value by enhancing the streamer's video. Since there was a wide variety of accessories that streamers recommended, we sorted them by monetary cost. Note that unlike other design space dimensions, video and audio accessories do not necessarily fit on a fidelity continuum since each kind of accessory serves a qualitatively different purpose. Thus, here we use monetary cost as a proxy for fidelity.

Mounts, stands: Mounts and stands provide stability and reduce vibrations for cameras. They also let streamers install lighting and cameras at the angle and height most conducive for good-quality video. These are cheap compared to the rest of the setup (starting around $15 USD), though some streamers suggested free alternatives like bending a metal clothes hanger to lean their smartphone camera against as a makeshift mount.

Greenscreen, reflectors, softboxes: Portable greenscreens can be used to hide the streamer's background environment for privacy. They also allow the streamer to display a digital background, which can add a personal touch without investing the money to build an elaborate physical set or stage behind them. Reflectors help redirect light which can help "light up both sides" of a streamer's face (V01), and softboxes soften the light coming from their lighting setup.

Capture cards: Camera capture cards are important for connecting DSLR and mirrorless cameras to the streaming PC. USB webcams do not need this extra hardware as they can interface directly with a PC, but streamers who use high-end camera setups or multi-PC setups need a capture card like an Elgato Cam Link [15] in order to complete their setup. Console capture cards are used in a similar way to capture footage from video game consoles.

4.3 Audio

Audio hardware allows streamers to increase engagement by speaking to viewers and manage audio levels for software (e.g., a game) or content (e.g., a YouTube video clip) that the streamer is showing. Audio is seen by some streamers as the most critical upgrade that novices can make to improve quality. For instance, V32 said:

> "In the film industry we have a saying that 60 percent of your film is audio. But when it comes to streaming on Twitch or generally streaming a lot of the time, it's actually 100 percent because people put you on in the background or they play a game or they do something else. So having good audio is absolutely crucial."

Streamers mentioned three audio-related dimensions (Figure 2):

Figure 9: A high-fidelity XLR microphone on an adjustable boom stand (with two DSLR cameras in the background near the monitor).

Figure 10: A hardware audio mixer that supports connections with XLR microphones and other digital audio sources. It provides buttons for muting individual sources, applying sound filters and voice effects to each, and physical sliders for fine-tuning audio levels.

4.3.1 Microphones. These broadcast the streamer's voice and external sounds like musical instruments they are playing.

Built-in/headset: Microphones that come built into webcams or headsets are the lowest-fidelity choice and not recommended by experienced streamers. That said, budget-conscious streamers find that a gaming headset is a good starting option when nothing else is available, and many streamers mentioned how they originally started with one.

USB: USB microphones are perceived as medium-fidelity and can be found at affordable prices ($30-150 USD). Since USB mics have integrated amplifiers and DACs (digital-to-analog converters), they do not need additional audio hardware, which makes them easier to get started with. However, some streamers mentioned they had issues with the integrated mixers that come with USB microphones and that the quality of the integrated amplifiers and DACs can be sub-par.

XLR: Figure 9 shows an XLR microphone, which is a professional-level option for streamers who want to get the best sound "because they send a balanced signal that isolates noise" [64]. These capture an analog signal to send to an audio interface (see Section 4.3.2) that converts it to digital to send to the computer. XLR microphones can get expensive ($400+ USD), but there are lower-end ones that can open up more options down the road because streamers can upgrade different parts of their audio setup (e.g., buying a better audio interface) without having to buy a new microphone.

4.3.2 Mixers. This dimension encompasses the range of hardware and software interfaces needed to mix and manage audio inputs/outputs. Audio mixers are an important part of a streamer's setup as it allows them to adjust audio levels like sensitivity, gain, and volume to react to whatever is happening live during a broadcast. For example, V06 stated that desktop audio should be set at 50-60 percent while the streamer's microphone audio should be at 100 percent in order not to drown out the streamer when the applications they are streaming get too loud.

Built-in: The lowest-fidelity audio interface is simply using the built-in audio mixing capabilities of broadcasting software (e.g., OBS) or the operating system (e.g., Windows audio level controls). This is a simple and free solution for those who do not want to adjust or configure the complex controls that more advanced software or hardware provide.

Software mixer: For those using USB microphones or who desire finer-grained sound control, streamers pointed out several software mixer options. For example, Voicemeeter Potato [5] is an audio mixer that can manage any audio device connected to the streamer's PC. However, some streamers had reservations about software solutions for audio mixing as it can require a lot of configuration and may be taxing on the CPU. For example, V03 drew up a diagram that she uses when she needs to debug any audio issues "and it feels like my brain needs to do back-flips to understand it all."

Hardware mixer: The highest-fidelity option is a dedicated hardware audio mixer, which is required for connecting high-end XLR microphones (Figure 10). These interfaces can also come with hardware adjustments for sound levels so that a streamer can adjust their sound levels without operating additional software.

4.3.3 Accessories. Similar to video accessories in Section 4.2.3, here we sort recommended audio accessories by cost:

Existing furniture for soundproofing: Using curtains, drapes, and rugs to reduce echo in the room the streamer is in can improve sound quality when streaming from locations with poor acoustics, such as rooms with concrete floors or large windows. These options are usually free or low-cost since they use the streamer's existing household furnishings.

Pop filter: This is a $10-20 USD cover that protects the microphone's condenser to prevent unpleasant popping noises when streamers speak with B or P sounds. It is frequently recommended as a low-cost way to improve audio quality.

Stands, mounts, boompoles: These accessories can prevent noises that occur when streamers hit their keyboard or desk too hard. An adjustable boom arm is preferred since it saves space and allows the microphone to freely move.

Professional soundproofing: While using existing furniture to lower ambient sound can help and "is one of the key ways to cut down on audio reverb" (V11), many streamers invest in professional

soundproofing such as modular panels of foam or other material installed on walls or ceilings. Some believe this to be a worthy investment ($100s-1000s USD) as "it is hard to attract viewers if you sound like you are streaming at the end of a sewer pipe" (V05).

5 DISCUSSION: TRENDS, CHALLENGES, AND OPPORTUNITIES

We now zoom out from individual design space components to pose four broader questions inspired by our analysis:

(1) How can we help livestreamers integrate many separate components into a unified setup?
(2) How can we help streamers manage the complexity of their equipment while broadcasting live?
(3) How can we teach novices to incrementally upgrade their setups without getting overwhelmed?
(4) How can livestreaming setups inspire future tools for remote work and education?

5.1 How Can We Help Livestreamers Integrate Separate Components Into a Unified Setup?

While the acquisition of higher-end equipment is one barrier to increasing stream fidelity, streamer frustrations also stemmed from the complexity of integrating all of the hardware and software together and making the correct configurations to properly use that equipment with one another. When streamers run into issues and need to debug their systems, it can be difficult to navigate the complexity of a high-fidelity stream setup, especially because not every streamer will have the technical expertise to dive into configuring each piece of technology in it. For example, V19 said the following about upgrading to a dual-PC setup:

> "I was so stressed! If you're also setting up a dual-PC setup, don't worry. I understand your stress. Been there, done that! I get it. This video is going to consist of all of the technical difficulties that I ran into while setting up my new setup. There's plenty of tutorials online that can say 'hey here's exactly how to do this,' but they never tell you what happens if you run into a brick wall."

While the streamers in our videos attempted to thoroughly explain their setups, they often left useful knowledge unsaid. With the vast amount of equipment to individually configure, plus further integration of this equipment with broadcasting software, streamers might not remember to share all the details of the options that they used and the 'insider knowledge' required to debug their setups. So, how can we help streamers share this knowledge with each other to enable novices to get past the frustrations involved in integrating their equipment together?

To address this challenge, we envision a novel tool that can elicit knowledge from streamers, collect data on both the physical and digital aspects of a stream setup, and share it online. This tool can identify knowledge gaps in the integration of components to guide streamers who are using similar components. Whenever a relevant component combination is detected within a streamer's current setup, a set of verified physical and software configurations can be presented to them. This tool could also provide a way for streamers to create technical blogs and vlogs where they share frustrations and successes while integrating their equipment into a complete setup. These blogs/vlogs can be synthesized, organized, and made searchable so that novices using similar components can quickly find example walkthroughs that are more targeted to their own goals. This tool might also detect issues with equipment and integration between parts of the setup that the streamer has acquired and present contextually-relevant fixes found online.

5.2 How Can We Help Streamers Manage the Complexity of Their Equipment While Broadcasting Live?

The challenge doesn't stop once the initial setup is done. Running these streaming setups live while playing games, musical instruments, creating art, etc. is difficult since the streamer is often alone. Online moderators can sometimes help with operating web extensions that allow them to control scene selection and other interactions, but since *the streamer is both the director and performer* they need to be able to make changes to their stream themselves on-the-fly. For example, a streamer might need to adjust multiple audio controls for the same microphone, muting themselves in the in-game voice chat so that they can talk with viewers while playing a game without distracting the other players they are with, or mute themselves from viewers when they need to speak to someone privately. Artists and chefs may need to swap between multiple camera angles as they work and move around in their studios or kitchens. And variety streamers [25] may need to change their stream scene layout with each new game or app they open so as not to accidentally obscure important UI elements that are inconsistently placed between each application. Given these challenges, how can we support these streamers into becoming their own single-person live production crew?

To this end we envision a novel tool that can automate critical parts of livestream production. For instance, when this tool detects potential stream overlay or layout issues, it can warn the streamer that their existing scene may need to be modified to prevent hiding parts of an application's UI that might be interesting for viewers (e.g., the health bar of their game character). When a new application is launched, the tool can provide recommendations for where the facecam and other parts of their stream overlay should be positioned, informed by a heatmap of previous streamer layouts within these specific apps. To control scene selection, this tool might detect movement on other cameras in a multi-camera setup and switch to a scene that shows the most active camera to viewers. However, such a feature would need to allow the streamer to define when this automation was allowed or prohibited (e.g., during a game the streamer would likely not want to auto-switch to a wide-angle shot of their room). Further, this tool might detect what applications are being used and select scenes based on what application is in the foreground of the streamer's PC and the current state of that app. For example, when a programming streamer launches their IDE right after talking with their viewers for a bit, this tool could control OBS Studio to change from the 'just chatting' scene to a 'programming' scene that shows only the IDE. If they encounter a code error while debugging, perhaps the tool switches to an 'error'

scene that zooms into the stack-trace within the command-line and plays a sad violin music clip for the audience.

5.3 How Can We Teach Novices to Incrementally Upgrade Their Setups Without Getting Overwhelmed?

Livestreaming equipment can be difficult to acquire and set up all at once. It can be hard to balance one's targeted stream fidelity with the monetary investment one has to make to achieve it. Some streamers noted that everyone needs to find a balance that works for them. Ironically, watching streaming setup walkthrough videos may make novices feel intimidated by everything on display. For example, V16 shared their frustration with streaming setup videos "because I find these videos somewhat pretentious from the get-go. This whole thing [my streaming setup] is 10 years' worth of collecting stuff. It looks more impressive and expensive than it actually is, and some of the stuff I even got for free [from sponsors]." So how can streamers incrementally upgrade their setup without getting overwhelmed?

V13 recommends starting one piece at a time "because livestreams are hard. It is a lot going on, especially if you're directing it at the same time that you're in it and featured in it. So, for me I would actually try to work on all of this technology one piece at a time." But even with this advice, novices may need more detailed guides of how to incrementally ramp up without getting overwhelmed. For example, a novice streamer may begin their streaming journey with just a USB microphone, no external hardware audio or video interfaces, a budget webcam, and a single laptop running OBS Studio to broadcast. From here there are many paths that they could go down for smaller upgrades to improve their stream's production quality. They might first upgrade their USB microphone to an XLR one, but with this upgrade they must also find an audio interface that allows them to connect their higher-fidelity microphone. They might also upgrade their webcam to a DSLR camera, which will require further investment into accessories like a capture card. Or they might switch from software-based broadcasting to a hardware video switcher, which may itself also take over audio interfacing duties. There are many possible paths for a streamer to go down when making upgrades, which could result in choice overload.

To address this challenge, we envision a tool that recommends iterative upgrades to novice streamers given their current starting point and budget constraints. But how would these novices know what to upgrade first? While viewers of the stream may be able to give feedback to the streamer on what generally needs improvements (e.g., camera quality, audio noise, etc.), we believe this tool should also detect 'low-fidelity' stream symptoms and predict the likely causes behind them. For instance, video pixelation might lead to a recommendation to switch to NVEC encoding, or a noisy audio signal might be improved with a better microphone and audio interface setup. Viewers might still be leveraged through polls and chat feedback presented to the streamer so they can visualize areas of improvement for their own broadcast. Another alternative is to present novices with upgrade paths that previous streamers with similar setups went down, including the alternatives and low-cost repurposed 'hacks' they used. It can support streamers by exposing various existing setups and configurations, so that a streamer can pick and choose different elements of production fidelity that they want to reflect in their own streams. Finally, it can present before-and-after comparisons of specific components – i.e., how did this upgrade affect other streamers who tried it? This knowledge will allow streamers to make more informed decisions on whether the upgrade is worth it for the production quality they desire.

5.4 How Can Livestreaming Setups Inspire Tools for Remote Work & Education?

As hybrid and remote work arrangements grow more widespread in light of the current global pandemic, more people are thinking about improving their home office setups. Since a major form of communication between coworkers is via online video conferencing platforms like Zoom or Microsoft Teams, many of us are now thinking about improving the production quality of how we present ourselves in this format. Using a low-fidelity setup (e.g., a laptop's built-in webcam and microphone) during online meetings for extended spans of time can lead to 'Zoom fatigue'[18, 49, 63].

Studying the equipment setups of professional livestreamers may inspire us to improve our 'personal amateur livestreams' that we broadcast as remote workers and students, which could in turn improve long-term remote work and learning arrangements. Specifically, improvements to video quality and livestream-inspired interaction techniques might form greater connections between team members or classmates who cannot meet in-person.

We optimistically believe that livestreamers can be trend-setters here, and we envision the home office of the future to look more like the high-fidelity streaming setups of the present. While not all approaches to high-fidelity streaming are appropriate for the virtual workplace or lecture hall, having increased control over virtual self-presentation can potentially benefit both workers and students. However, more research needs to be done to understand whether applying these higher-fidelity setups within the context of a business or university actually brings real benefits, or whether more widely-accessible low-budget setups are sufficient. What is the balance of cost and fidelity required to be effective here?

6 CONCLUSION

In this paper we presented a content analysis of 40 livestreaming setup videos and distilled their features into a ten-dimensional design space consisting of broadcasting, video, and audio equipment. This design space captures the contemporary trends in streaming setups, along with challenges and design opportunities for improving the integration of components and helping novices get started. More broadly, we propose that the technical knowledge that livestreamers possess can potentially help a much larger population of people around the world who are now working and learning remotely. In the coming years, we predict that more of our remote and hybrid workspaces may resemble what we see professional livestreamers using today. Thus, we hope that this research enables people to leverage design spaces to design spaces.

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