Exploring Non-Urgent Smart Home Notifications using a Smart Plant System

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ABSTRACT

With the rise of the Internet of Things, home appliances become connected and they can proactively provide status information to users. Facing a steadily increasing number of notification sources, it is unclear how information from smart home devices should be provided without overloading the users' attention. In this paper, we investigate the design of non-urgent smart home notifications using a smart plant system. Based on feedback from focus groups, we designed four notification types and compared them in an eight-week in-situ study. We show that notifications displayed on smart home devices are preferred to those received on smartphones. Event-based notifications are unobtrusive, actionable and are preferred to persistent notifications. We derive guidelines that address the need of being in control, opportune locations for notification delivery at opportune moments, notification blindness, the importance of discretizing continuous information, and combining related notifications.

CCS CONCEPTS

• **Human-centered computing → Human computer interaction (HCI)**; **Ubiquitous and mobile computing**; *Field studies*; *Ambient intelligence.*

KEYWORDS

Attention management; notifications; smart home; Internet of Things.

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1 INTRODUCTION

With the rise of the Internet of Things (IoT), our living and working environments are significantly changing. In order to function optimally, smart home devices need to inform their users about many kinds of information, primarily when maintenance is required. For example, robotic vacuum cleaners have to inform the users when the dust bin needs to be changed. While some of the provided information might be important, most information will be neither urgent nor necessarily require immediate attention. Contemporary smart home devices inform users about their states mainly through mobile notifications on the user's smartphone. However, mobile notifications already provide a large amount of information proactively, including incoming messages, upcoming appointments, or available updates [34, 39]. A body of work shows that a stream of mobile notifications can overwhelm users and cause negative effects, including distraction, interruption from current tasks, and stress [2, 12, 19, 23]. When smart devices start to provide a large number of additional notifications on the users' smartphones – as current smart home devices do – these negative effects will be amplified. Consequently, the interfaces of future smart devices have to be designed in the light of an already overwhelming amount of notifications.

Previous work investigated the acceptance of home reminder systems that could use notifications [28, 44, 45], but it remained unclear how smart home notifications should be designed. Voit et al. provided first insights about smart home notifications, but they only asked potential users to provide their opinion about possible locations [46] and modalities [49] for smart home notifications in an approach with limited ecological validity. What is missing is an assessment of the fundamental design choices for smart home notifications. However, studying non-urgent smart home notifications is challenging as few users own smart home devices that support notifications and even if they do, the devices are heterogeneous which prevents a systematic assessment.

In this paper, we conduct an in-situ study in the participants' homes to understand the user experience of non-urgent smart home notifications by gathering feedback with a high ecological validity and over an extended period of time. To that end, we designed and implemented a system that notifies users about the state of a plant. The plant system represents on a single representative source of notifications, which enables systematic assessment. We chose to use a plant as it is universally acceptable in a home environment and pleasant for diverse users so that its aesthetic qualities do not bias the study. Further, it limits the burden on the user and is easy to deploy. Smart plant systems that inform users about the plant's state are commercially available.Previous research also explored the illumination of real and artificial plants [3, 46, 48, 50]. However, the fact that a limited number of users owns smart plant systems that support them in taking care of their plants enabled us to study notifications from smart plant systems without bias caused by past use of smart plants.

We use the plant system to empirically explore the following research questions: (**RQ1**) Should non-urgent smart home notifications appear immediately after an event happens or persistently inform about device states? Displaying notifications once an event has happened is subtle but might not be seen in time, persistently displaying the state might be too salient but ensures better visibility. (**RQ2**) Should non-urgent notifications be provided on the users' mobile devices or should they be displayed close to the smart home devices?

As no design guidelines for such systems exist, we conducted two focus groups to guide the design. Through an eight-week in-situ study we explore fundamental design choices for non-urgent

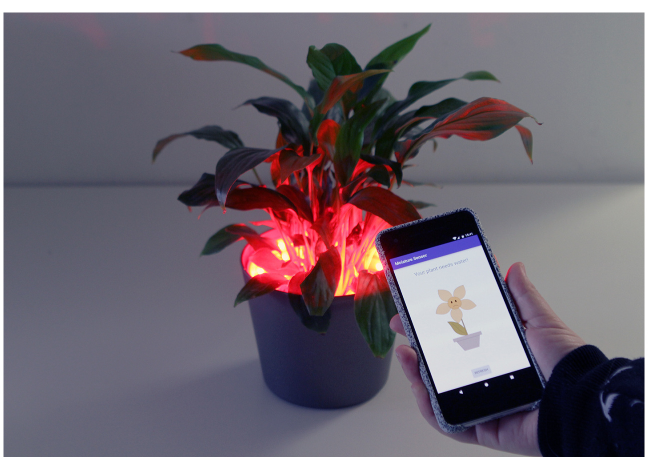


Figure 1: Smart plant system informs the user with a display at the plant pot and a smartphone app.

smart home notifications. Based on the results, we provide design guidelines that address the need of feeling in control, opportune locations for notification delivery at opportune moments, notification blindness, the importance of discretizing continuous information, and combining related notifications. The contribution of our work is twofold: (1) We systematically analyzed different notification strategies for non-urgent smart home notifications using a smart plant as a research probe. (2) From the findings of the study, we derive guidelines that support designers and practitioners in developing future IoT notification systems.

1.1 Research focus: Non-urgent smart home notifications

We anticipate that smart home devices will inform users about an increasing amount of information in the future. More and more devices will become connected and transfer their status to the digital domain. As simply making the device status available cannot scale when the number of devices increases, current smart home devices already use notifications to inform users about status changes. Notifications have been defined as visual cues, auditory signals, or haptic alerts generated by an application or service that relays information to a user outside of the current focus of attention [19, 39]. In a smart home context, notifications about many status changes do not necessarily require immediate attention. For example, users can be informed when smart home devices such as washing machines, dryers, or dishwashers are finished with their respective processes. Further, smart home devices can inform their users about upcoming home tasks such as defrosting or descaling their smart home devices, e.g., freezers or coffee machines and kettles, changing the dust bag of a robotic vaccuum cleaner, or watering plants. Finally, users can be informed about interesting or useful additional information. Calendars can inform them about garbage collection dates and upcoming events. Fridges can inform about their stocks and the grocery expiry dates. Smart TVs can inform the users about the availability of new episodes of the users favorite series (e.g., Netflix, etc.).

Extending the definition of notifications [19, 39], we define non-urgent notifications as *visual cues, auditory signals, or haptic alerts generated by an application or service that relays information to a user outside of the current focus of attention where a response can be delayed by up to several hours or even days.* While an extensive body of work investigated how to effectively deliver prompts that make the user act immediately [38], much less attention was devoted on communicating information that may be acted upon at a later time. To explore this gap, we focus on *non-urgent smart home notifications.*

2 RELATED WORK

Our work builds upon three research strands: (1) reminder and notifications at home, (2) ambient information systems, and (3) mobile notifications.

2.1 Reminders and notifications at home

A body of work focused on how users with disabilities can be supported through ambient assisted living and smart reminders [6, 13, 27]. People from all age groups likely forget tasks in and around their homes [28]. Specifically, McGee-Lennon et al. found that middle-aged and younger people tend to forget more diverse tasks than older adults. Thus, there is a need for home reminders supporting users of all age groups.

Acceptance is important for home reminder systems. If a reminder system is not accepted, users might turn it off or ignore displayed reminders [28, 44]. Reminder systems are more accepted when they use metaphors or reminding strategies users are already used to [28]. Crabtree et al. identified prime sites for ubiquitous computing, e.g., tables or notice boards, which habitually draw the users' attention when they manage their communication at home [10]. Further, the acceptance of displayed notifications in domestic environments depends on the urgency of the notification [44, 45]. High-urgency notifications are more accepted than non-urgent ones [44, 45]; medium-urgency notifications were accepted when they were unobtrusive [45]. In contrast, low-urgency notifications are not accepted [45]. Low-urgent notifications should be delayed until the urgency increases or dismissed if the urgency does not increase. However, the user's current primary task does not influence the acceptance of the notifications [45].

Devices in smart environments compete for users' attention. Hence, there is a need to design notification systems that inform the users through displaying subtle information [11]. Bourgeois et al. found that delayed as well as real-time feedback are not appropriate tools to support demand shifting behavior; instead proactive suggestions and contextual control supports users in organizing their daily lives by micro-planning and micro-scheduling of household activities [7]. Further, notification systems in the home should support natural and transparent interactions [20]. A survey revealed that users prefer receiving smart home notifications on their smartphones [46]. Further, visual cues are preferred for the representation of smart home notifications in the physical environment [49]. The modality used to deliver notifications affects the time required to perceive notifications, but it has no effect on disruptions [51], nor the performance of a home task [52].

2.2 Ambient information systems

Ambient information systems display information in the periphery of the user's attention using aesthetic displays [21]. Such systems can be either integrated into existing objects or use additional devices to display information in the surroundings [43]. Since these devices are visible in the users' environment, aesthetic aspects are important factors for their acceptance [37]. Ambient information systems can use visual [18, 29, 55], auditory [1], tactile [36], or olfactory [5, 8] cues to deliver information to the users.

Previous work investigated how ambient information systems should display information [24, 25]. Matthews et al. suggested that the optimal information representation depends on the information's importance and how much attention the user needs to spend [24]. Depending on the importance of the information the users should either be able to ignore it or the system should make them aware of the information. For very important information, the system should be able to interrupt the users from their current primary tasks. Furthermore, the displayed information in ambient information systems should be perceivable at a glance [24]. Therefore, information should be displayed unobtrusively and in an abstract way, e.g., using ambient light systems. Matviienko et al. found that the most prominent encoding parameters of ambient light systems are color, brightness and their combination [26].

2.3 Mobile notifications

Today, apps inform users proactively through mobile notifications using visual, auditory, or tactile cues [19]. Notifications on smartphones inform their users mainly to support communication [34]. Users value notifications from messaging apps and notifications containing information about people or their current context [39]. Further, users prefer to receive notifications on smartphones, but the proximity to devices, if they are currently used, and the user's current location affect if users are willing to receive notifications on their other devices [53].

Chang et al. investigated the perception of mobile notifications. They found that only 62% of the notifications received were seen by the users [9]. In addition, Exler et al. showed that notifications displayed using tactile or auditory feedback were most perceptible [14]. However, auditory notifications were perceived as too annoying, disturbing, and obtrusive for everyday use [14]. In contrast, tactile notifications were perceived as more private and subtle; however, this can lead to awkward situations when others cannot foresee an action arising from such a notification [17].

A body of related work investigated negative effects caused by notifications [2, 19]. Iqbal and Horvitz showed that email notifications on desktop computers cause distractions from primary tasks [19], increasing the mental workload [2]. Turning off notifications [35] and blocking non-work related distractions from social media [22] lead to increased productivity and less distractions. However, users feel less responsive and less connected to their social contacts [35]. Some users experience more temporal demand and stress when receiving notifications [22]. Another strand of prior work aimed to reduce distractions by delaying incoming notifications to opportune moments, such as breaks between tasks [15, 33].

2.4 Summary

Previous research investigated the acceptance, effects of different modalities, and possible locations for displaying smart home notifications. Ambient information systems display non-urgent information in the users' periphery that they can access at a glance. Current technologies such as smartphones inform their users proactively using notifications. Due to the novelty of the topic, there is little research that investigates how non-urgent smart home notification systems should be displayed and if they should also use established notifications.

3 FOCUS GROUPS

We conducted two focus groups to explore the design of smart plant systems. Both focus groups lasted approximately 50 minutes and were audio-recorded. One of the groups was conducted in a living room; the second group was conducted in a meeting room. To gain insights about design alternatives for smart plant systems, we asked the participants to draw their suggestions into provided sketches of a plant pot. Further, we provided snacks and beverages as remuneration.

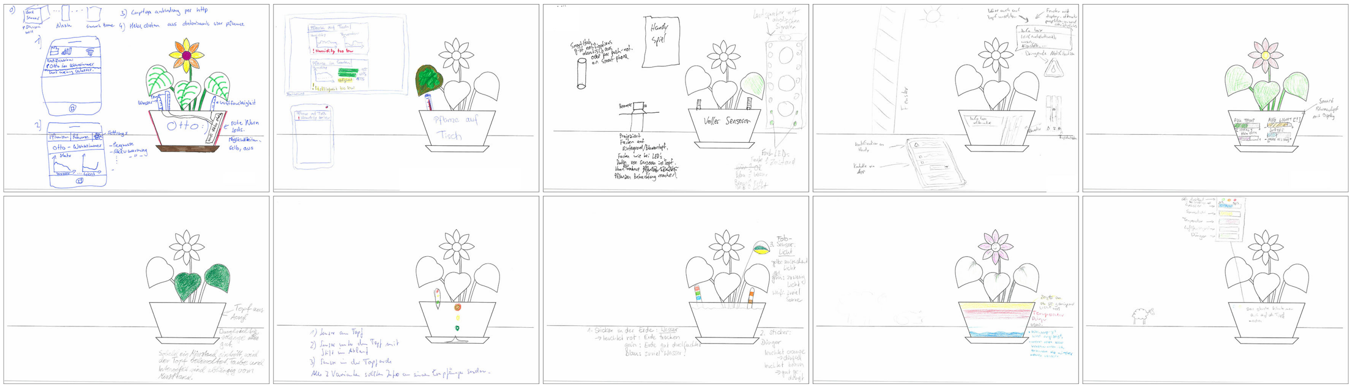


Figure 2: Sketches of smart plants systems created in the focus groups by the participants.

3.1 Procedure

At the begin of each focus group, we asked participants to fill out a consent form and a demographic questionnaire. Afterwards, we gave a presentation to introduce the topic of notifications in smart home environments, ending with a brief outline of the focus group.

First, we collected ideas about which kinds of information a smart plant system should convey. In a follow-up question, we asked how this information should be displayed. Therefore, we invited participants to draw their suggestions on the provided sketches.

Afterwards, the participants presented their sketches and we discussed their advantages and disadvantages. If not addressed, the researcher explicitly asked about the use of light-, text- and symbol-based visual notifications to display the state of the plant in the home environment. Finally, we discussed with the participants how their ideas can be realized.

3.2 Participants

Ten participants (4 female, 6 male) took part in two focus groups (5 participants each). For one of the focus groups, we deliberately chose participants who did not regularly care for plants to take inexperienced users into account. This enabled us to investigate also requirements to facilitate new routines of novice users. The first group consisted of three students, one computer scientist, and one housewife. Participants were between 22 and 62 years old ($M = 30, SD = 16.10$). Four participants mentioned took care of plants regularly. The second group consisted of five students, aged between 22 and 23 ($M = 22.4, SD = 0.55$). None of the participants in the second group took care of plants regularly.

3.3 Results

The results are based on the group discussions and sketches that were created during the focus groups. The researcher who led the focus groups transcribed the discussions, identified themes, and categorized the ideas in the sketches.

All participants were interested in information about the plant's water level. Other types of information they were interested in include light requirements (4 participants), fertilizer and pests (4), temperature (3), and humidity (3).

Participants suggested to display information from the plant on a smartphone (9), directly at the plant, or plant pot (7), and a central display in the home (7). Examples for the sketches created are shown in Figure 2. On the smartphone, statistics could be displayed in an app and push notifications could be used to alert users about the state of the plant.

Six participants agreed that the information should be color-coded, but also stated that complex color-coding should be avoided. Examples for color-codes include red for dry soil, green for enough water, and blue for too much water. Light conditions could be coded as yellow for not enough light, green for enough light, and white for too much light. Orange could be used to indicate the need for fertilizer, while brown could show that there is enough fertilizer. For the overall state of the plant, the colors red, yellow and green were suggested. A similar idea only uses a red color to indicate an action.

Further suggestions include progress bars, symbols, and text displayed on a nearby wall, or the plant pot. A textual percentage for the water level could be used, with values over 100% indicating overwatering. Seven participants were against displaying text on plant pots due to readability concerns. Similarly, five participants were concerned about using projection on a nearby wall to indicate the state, as readability would depend on the light conditions.

4 SMART PLANT SYSTEM

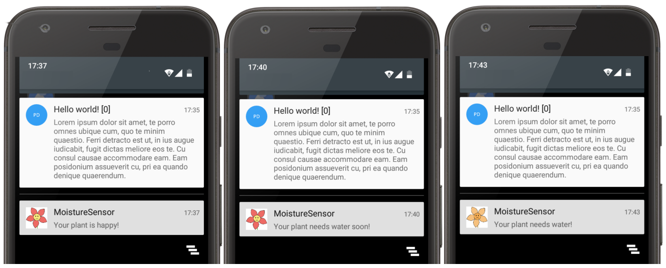
Based on the focus groups, we developed a smart plant system that informs about the plant's water level using a mobile application and an ambient display at the plant pot. The system differentiates between three states: (1) the water level is sufficient, (2) the water level will fall too low soon, and (3) the water level is too low.

4.1 Notification Types

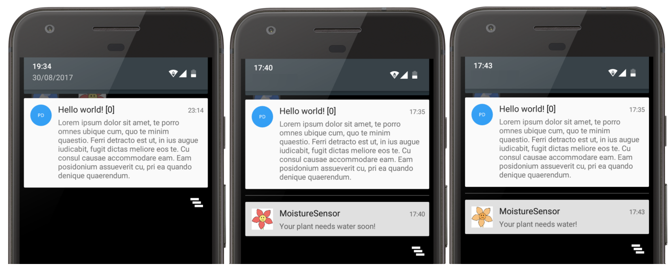
The smart plant system supports two notification strategies and two notification locations to inform the users. In case of the *event-based* strategy, the system only notifies the user if an action is required. The *persistent* strategy permanently displays the current water level. Both strategies can be displayed on either the plant pot or the user's smartphone. Thus, we implemented four notification types (cf. Figure 3): (1) The plant pot persistently shows the current water level or (2) use the event-based strategy to notify the user when the plant needs water. On the smartphone, (3) the current water level is shown through a persistent notification or (4) the

(a) Persistent notifications: on the plant pot

(b) Event-based notifications: on the plant pot



(c) Persistent notifications: on the smartphone



(d) Event-based notifications: on the smartphone

Figure 3: Images of the supported notification types including their behavior in all states. The persistent notification strategies always display the current state, while notifications in the the event-based strategy occur only when an action is required.

user is notified by an event-based notification if the plant needs water.

We use the traffic light metaphor to display the water level directly at the plant pot. The color-coding matches the supported states of a plant. In the persistent representation at the plant pot, the plant is augmented in green light when the water level of the plant is sufficient. The LEDs light in yellow when the water level falls too low soon and in red when the plant needs to be watered because the water level is too low (see Figure 3(a)). For the event-based representation, we use the same color coding, but turn the LEDs off when the plant has sufficient water. For both notification strategies on the plant pot, the LEDs are automatically turned off at night. The intervals at which the LEDs are turned off are configurable.

We developed an Android app to display the plant's current state on the user's smartphone. Using notifications, the app informs about the plant's water level. For the mobile notifications, we used different icons of a plant with different facial expressions to match the states of a plant. Here, a smiling plant is displayed in the notification center if the water level of the plant is sufficient, a neutral face is displayed when the water level falls to low soon and a sad and decayed plant is displayed if the water level is too low (see Figure 3). For the persistent strategy, a persistent notification is shown in the device's notification center that displays the current state (cf. Figure 3(c)). This notification is shown in the bottom of the notification center and cannot be dismissed by the user. Further, no visual, tactile, or auditory cues are used when state changes occur. For the event-based strategy, the app triggers push notifications if the plant's water level will be too low soon or is already too low. Push notifications can be dismissed by the user and are shown at the top of the notification center and, additionally, on the lock screen and status bar. If a notification was dismissed by an user, the app will not re-trigger the notification. The notifications are delivered with the device's default notification sound and vibration pattern but may be silenced based on the device's ringtone setting.

5 IN-SITU STUDY

To gain an understanding of how to display future non-urgent smart home notifications we conducted an eight-week long in-situ study using the developed smart plant system.

5.1 Study Design

We used a within-subject design to investigate the different notification types. Hereby, we studied two independent variables: (1) the notification location: on-object, or on-smartphone, (2) the strategy of the notification: persistent, or event-based. We used four supported notification types (shown in Figure 3). Each notification type was deployed for two weeks. We used a Latin square design to assign the conditions. For the study, we deployed our smart plant system with plant (Peace Lily) for eight weeks in the participants' homes. The participant could choose where to place the plant (see Figure 4).

5.2 Participants

We invited 20 participants (11 female, 9 male) through university mailing lists and social media. The active use of an Android smartphone was a requirement for the participants. Participants were compensated with EUR 30. We excluded three participants due to technical reasons (broken personal smartphone, internet outage, and a broken micro-controller used for the control of the

(a) Kitchen (b) Living room (c) Dining table (d) Private office

Figure 4: Examples for placements the participants chose to place our smart plant system in their homes during the study.

LEDs and measuring the plant's water level). The remaining 17 participants (8 female, 9 male) were between 21 and 60 years old (M=31.94, SD=12.45). Seven participants were students; one a Ph.D. student, and seven were employees. One participant was a florist (professional in taking care of plants). Another participant was self-employed, and one was a housewife. Ten participants were living together with their families, four with their partner, two lived in shared apartments with friends or colleagues, and one participant lived alone.

Four participants had no plant in their homes before the study, six had up to five plants, four participants had up to ten plants, and another four participants had more than 20 plants. Eight participants placed their plants in multiple rooms; three placed their plants in a single room and two only owned outdoor plants. Two participants had plants on their balconies as well as in their gardens. Two participants strongly disagreed to have a green thumb; three disagreed, five were neutral, four agreed, and three strongly agreed.

5.3 Procedure

At the beginning of the study, we visited participants in their homes, asked them to sign a consent form and answer the demographic questions. We set up the smart plant system according to the first condition and installed, if necessary, the Android app on the participants' smartphones. Also, we explained how our system will notify the participants in the first condition. The study started on the next day.

After two weeks, we asked participants to assess the notification type by answering a questionnaire. Further, we set up the smart plant system for the next notification type. This process was repeated for the remaining conditions. In the questionnaires for the notification types, we asked the participants to rate the notification type using four statements from "Strongly disagree" (1) to "Strongly agree" (5).

- **(Q1)** I like this notification type.
- **(Q2)** This notification type is useful.
- **(Q3)** This notification type is easy to perceive.
- **(Q4)** This notification type is disturbing.

At the end of the study, we asked participants to rank the notification types and conducted semi-structured interviews. In the interviews, we asked how they experienced the notification types and explored how non-urgent smart home notifications should be delivered in the future.

6 RESULTS

In the following, we present the results of the study, quantitative and qualitative.

6.1 Quantitative Analysis

We applied the Aligned Rank Transform (ART) [54] procedure to participants' ratings to align and rank our data. We used two-way ANOVAs to determine significant effects of the independent variables location and strategy on participants' ratings (cf. Figure 5).

Event-based notifications on the plant pot were most liked by the participants, followed by event-based notifications on the smartphone, persistent notifications on the smartphone and persistent notifications on the plant pot. We found no significant effects for location [$F_{1,48} = 0.00, p = .965$] but a significant effect for strategy [$F_{1,48} = 10.47, p = .002, \eta^2 = 0.179$]. Event-based notifications were significantly more liked than persistent notifications. We found no significant effect for the interaction location×strategy [$F_{1,48} = 0.49, p = .488$].

Event-based notifications on the smartphone were considered most useful, followed by event-based notifications on the plant pot, persistent notifications on the plant pot, and persistent notifications on the smartphone. We found no significant effects for location [$F_{1,48} = 1.58, p = .214$] but a significant effect for strategy [$F_{1,48} = 11.88, p = .001, \eta^2 = 0.198$]. Event-based notifications were rated significantly more useful than persistent notifications. We found no significant location×strategy interaction effect [$F_{1,48} = 1.69, p = .200$].

Event-based notifications on the plant pot were rated easiest to perceive, followed by persistent notifications on the plant pot, event-based notifications on the smartphone, and persistent notifications on the smartphone. We found a significant effect for location [$F_{1,48} = 15.19, p < .001, \eta^2 = 0.240$]. Notifications on the plant pot were rated significantly easier to perceive than notifications on the smartphone. We found a significant effect for strategy [$F_{1,48} = 10.57, p = .002, \eta^2 = 0.180$]. Event-based notifications were rated significantly easier to perceive than persistent notifications. Also, we found a significant location×strategy interaction effect [$F(1, 48) = 8.18, p = .006, \eta^2 = 0.146$].

Event-based notifications on the plant pot were rated least disturbing, followed by event-based notifications on the smartphone, persistent notifications on the smartphone, and persistent notification on the plant pot. We found no significant effect for location

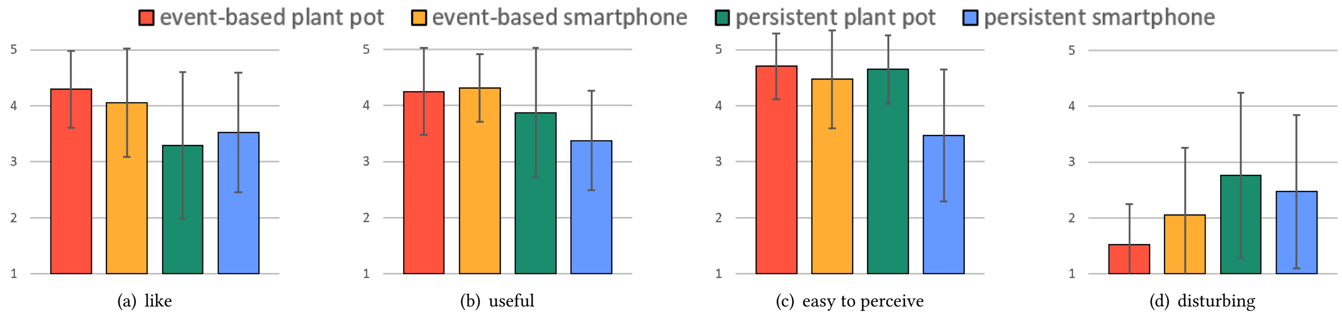


Figure 5: Ratings of different notification types. Error bars show the standard deviation. (1 = strong disagree, 5 = strong agree)

$[F_{1,48} = 0.07, p = .789]$, but a significant effect for strategy $[F_{1,48} = 11.42, p = .001, \eta^2 = 0.192]$. Persistent notifications were rated as significantly more disturbing than event-based notifications. We found no significant interaction effect for location×strategy $[F_{1,48} = 2.57, p = .116]$.

We asked participants to rank all notification types (see Figure 6). Event-based notifications on the plant pot were most often ranked first ($Md = 1$), followed by event-based notifications on the smartphone ($Md = 2$), persistent notifications on the plant pot ($Md = 3$) and persistent notifications on the smartphone ($Md = 4$). We, again, used the Aligned Rank Transform and a two-way repeated measures ANOVA to determine significant effects of the independent variables location and strategy on the participants' ranking. Notifications on the plant pot were significantly higher ranked than notifications on the smartphone $[F_{1,48} = 7.33, p = .009, \eta^2 = 0.133]$. Event-based notifications were significantly higher ranked than persistent notifications $[F_{1,48} = 31.53, p < .001, \eta^2 = 0.396]$. We found no significant location×strategy interaction effect $[F_{1,48} = 0.00, p = 1.000]$.

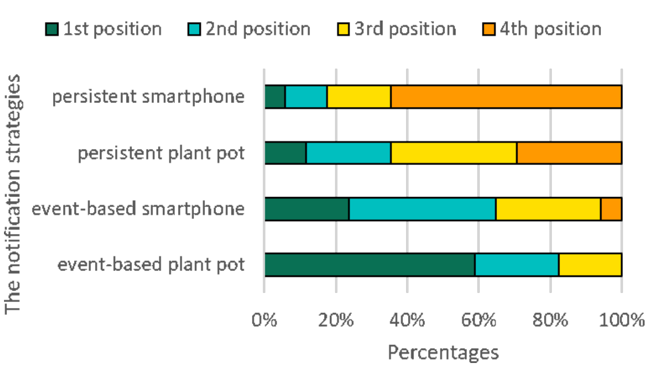


Figure 6: Ranking of the four notification strategies. (N=17)

6.2 Interviews

All interviews were audio recorded, and, afterwards, transcribed verbatim. We used thematic analysis [4] with open coding to analyze the interviews. Two researchers coded four representative interviews in parallel to establish an initial coding tree. After a review meeting, the researchers agreed on a coding protocol. The remaining interviews were then coded by a single researcher. Representative quotes were translated to English. We identified the themes: Situatedness, Context, and Future Use.

6.2.1 Situatedness. Participants reflected about the suitability of a smart plant system and captured factors influencing the acceptance of a smart plant system at home. The system was perceived as supportive by different types of users – users without "green thumbs" as well as expert users with busy lifestyles: *"I always wanted a small Bonsai tree, but I always forgot to water it. [Such a system] adds a character to the plants, and I get a feeling that the plant is there and needs something. " (P8, general)*

Participants commented extensively on the aesthetics of the smart pot and how it influenced their perception of an ambient notification system. Some felt that the persistent lighting provided too much feedback: *"The [persistent lighting] really got on my nerves. The plant was entirely in the background, and the colored lighting was what you perceived. " (P16, persistent plant pot)* Participants wondered if they would eventually stop noticing the notifications after some time: *"My experience is if I receive a [persistent] notification, the notification and also state changes [...] will end up in my internal spam filter and I don't perceive [it] anymore." (P15, persistent smartphone)* In contrast, event-based illumination, appeared to offer a more subtle and unobtrusive experience. *"I found the [event-based lighting], where the green does not appear at all, the most visually appealing. [The plant is illuminated] in yellow and red only for short times until you react [to the notification]. I found that not as annoying as the [persistent ambient lighting]." (P4, event-based plant pot)* Event-based notifications were also seen as more actionable and unobtrusive: *"I mean, obviously, it is more noticeable if [the plant] is only illuminated if it needs attention [because it needs to be watered]." (P11, event-based plant pot)*

Participants thought about supporting multiple plants. To reduce the number of non-urgent notifications on smartphones, participants suggested adapting established notification strategies by being notified once per day at opportune moments and opportune locations. *"[I could imagine] to receive a summary once per day. Notify me always at 8 pm then I am at home in any case and tell me these are the plants you should water now." (P1, general)* In contrast, participants were generally content with on-object notifications and remarked that it has high scalability. *"[The event-based ambient lighting shows me] which plants I have to water. I would keep it how it is. In the respect, that all plants are illuminated." (P8, general)*

Overall, participants saw a high potential for integrating ambient notifications for a smart plant system in a domestic environment. They were eager to benefit from the functionalities provided. Yet, whether or not a smart plant system could become a situated object in a home depended largely on how it would react to the usage context at hand.

6.2.2 Context. This theme describes how participants used and experienced the smart plant in context. The applicability highly depends on the location of the plant in the home: *"If you don't enter the room periodically, I think the phone would be better [to receive the] notification." (P12, event-based smartphone)*

Even if a smart home device was placed in a frequently visited location, participants were still concerned about forgetting to water the plant when they are too busy. *"If [...] the LEDs of the plant pot turn off from 11 pm to the next morning. It could be that I come home several days in a row around midnight and leave the house at 6 am in the morning nevertheless. Thus, it could happen that I am not at home when the plant [...] notifies me." (P15, persistent plant pot)*

Also, we observed that participants were concerned that they could not differentiate if the smart plant system was turned off (in the event-based strategy) or malfunctioning which could result in a dying plant. *"You never know if the system is still working correctly since there is no indicator [when the light is off]." (P9, event-based plant pot)*

Participants remarked that they sometimes receive notifications at inopportune moments where they cannot immediately react to a notification, e.g., when they are on the go and therefore not at home. One participant remarked that being unable to take immediate action leads to frustration: *"I was on the bus, or train, or some other place where I was bored. So I checked if there is something new and saw that I forgot the plant and it needs water. What should I do? I'm not there. It is not as useful as the light because when you see [the light] you are actually there" (P8, persistent smartphone)* In contrast, some participants enjoyed being aware of the state of their plant and required care during their day: *"[Through notifications I received on the way,] I was prepared that I should water the plant today" (P13, event-based smartphone)*

We observed two kinds of user behaviors when notifications were received on the go. One group dismissed notifications that were received in inopportune moments and usually forgot to water the plant when they arrived at home. *"If you are on the go and receive a push notification, you cannot act on it. Moreover, if you dismiss it, you'll not remember it when you're back home" (P1, event-based smartphone)* To counter this issue, some participants kept the notification in the notification center until they watered the plant.

Participants remarked that the system could be useful during longer absence at home: *"[The system] could make it simpler for many [people] to water [the plants of other] persons that are on vacation." (P11, event-based plant pot)*

All in all, the interviews revealed that users required a high degree of context-awareness. They expected that a smart plant system would reflect their complex routines and socio-temporal conditions and constraints.

6.2.3 Future Use. Participants provided suggestions for smart home notification systems in the future. They were interested in receiving notifications from a diverse set of other smart home devices that could support the users in their daily lives. Participants requested notifications about regular household tasks such as unloading the washing machine, or maintaining tasks such as changing the robotic vacuum cleaner bags: *"I would like to receive push notifications when the laundry process is finished. It happened to me that I made the laundry and forgot about [it]. Hours later I remembered when I went to bed that I still have to hang up the [textiles]" (P15, general)*

In addition to the supported locations for displaying notifications (i.e., on the smartphone and on-object), users suggested taking other existing devices (e.g., Smart TVs), or a central smart home display into account. *"[Such a smart home display] could be placed in frequently visited areas such as the living room. Also, it could be like a tablet so that you can carry it around. For example, you could sit outside in your garden, and you would be notified when the current processes of your [home devices] finished." (P11, general)*

In general, participants were positive about additional sources for notifications at home. We observed that they easily imagined going beyond a smart plant pot system.

6.3 Discussion and Limitations

Participants generally preferred receiving event-based notifications that were significantly more liked and perceived as more useful, easier to perceive and less disturbing than persistent notifications. The Situatedness theme revealed that event-based notifications gain the user's attention only when it is necessary and are experienced as an explicit reminders.

Participants liked notifications displayed on the plant pot more than notifications received on smartphones. Notifications displayed on the plant pot were rated as significantly easier to perceive and ranked higher than notifications received on the smartphone. We observed in the Situatedness theme that notifications displayed on the plant pot are subtle and can be easier integrated into participants' lives.

In the Context theme, we found that participants could immediately react when they perceived a notification that is displayed on-object. However, the usefulness of on-object notifications depends on the location of the notifying device. For example, on-object notifications are useful for devices that are located in frequently visited environments (e.g., kitchen). On-object notifications might be less useful than on-smartphone notifications for devices located in less frequently visited areas (e.g., in the basement).

Participants were concerned about being overwhelmed by notifications on their smartphones if such a system would support multiple plants; as we observed in the Situatedness theme. The system notified the participants only when it was necessary to water the plant, which occurred about twice a week. However, the number of smart home notifications users have to attend increases with the number of supported notification sources. In addition to plants, participants mentioned a broad range of further smart home notification sources that could support their daily routines. To avoid overwhelming users with smart home notifications, the notifications have to be designed carefully.

We observed in the Situatedness theme that participants expect that smart home devices reduce the effort required by the users. For example, a smart plant system should minimize the number of watering processes during the week by aggregating the watering of multiple plants. To further reduce the number of triggered notifications, the system should collect similar kinds of information during the day and notify the user only once. This can enable everyday smart artefacts to become inherent parts of situated interactions in the home, possibly creating a companion experience [31].

In the Context theme, we observed that participants were concerned that they could miss notifications. Participants were concerned that they could miss notifications on their smartphones because of the number of other notifications they have to attend. Also, they stated that they could miss on-object notifications when they are busy or do not frequently visit the room where the device is located. Furthermore, participants were concerned that they might not recognize when a system is malfunctioning. They explained that missing notifications could lead to forgetting to accomplish daily tasks. To counter this, participants suggested to deliver notifications at opportune moments and in opportune locations, e.g., when they are at home in the evening and are able to accomplish the upcoming tasks immediately.

One limitation of our study is that we deployed a single smart plant. Thus, participants received a small number of notifications generated by the system. However, the study enabled participants to reflect on the scalability of a smart plant system supporting multiple plants. Further, they made suggestions to reduce the number of non-urgent smart home notifications by collecting information and notifying the users at opportune locations and moments. Another limitation is that we let the participants decide on their own where they would like to place a plant in their homes. However, as there are architectural constraints for users where they can place specific smart home devices in their homes. For plants the location is determined by personal preference and requirements for the specific plants (e.g., light or temperature conditions). Therefore, we decide to give participants an agency as placing the plant in a predetermined location would create an artificial home environment. In addition that also contributes to ecological validity. Another limitation is that participants experienced only smart home notifications generated by a single smart home device. However, support to care for plants is a relevant use-case since smart plant assistants are already widely available. In addition, watering plants is representative for a range of other use-cases where users are informed about upcoming non-urgent tasks. We observed in the Future Use theme that the participants welcomed the possibility of receiving smart home notifications for other kinds of upcoming non-urgent home tasks similar to watering plants.

Previous work already investigated related questions. Vastenburg et al. investigated the acceptance of smart home notifications with different urgency levels in a lab study [45]. Their results showed that the urgency influences the acceptance of smart home notifications. As “low-urgent” notifications (e.g., watering plants) were not accepted by their participants, Vastenburg et al. suggested to delay these notifications until the urgency of the content increased or to skip such a notification entirely when the urgency is not increasing. In contrast, our participants also liked the concept of receiving notifications for non-urgent information as they wanted to be aware of upcoming tasks as we found in the Context theme. Furthermore, Voit et al. compared different locations to display notifications in an online survey [46]. They found that smartphones were generally preferred to display smart home notifications and ambient on-object notifications received lower ratings. In our study, participants preferred ambient notifications compared to notifications received on smartphones. This supports the results of a recent comparison of different evaluation methods that showed that an used method for the evaluation of smart artifacts can effect the results [47]. Especially as their results also showed that smart artifacts evaluated using an online survey received lower ratings than the artifacts evaluated in in-situ. Further, reasons for this differences could be that the participants of the online survey were only used to receive notifications on their smartphones, but our participants experienced smart home notifications using ambient lighting in their daily lives. We assume that the differences can be explained by the higher external validity of our study.

7 DESIGN GUIDELINES

We derived five guidelines from our analysis. Although these guidelines are derived using a smart plant system as a research probe, the analysis showed that the study enabled participants to envision also notifications from other devices.

7.1 Provide opportunities for the user to feel in control even when not interacting.

In the Context theme, we observed that participants were afraid to miss a notification or that the system is malfunctioning. While this might partially be caused by the prototypical character of the used system, it remains important to allow users to check the current status of the system. This extends Shneiderman’s rule of *feeling in control* [41] since it is not limited to the time where the user is interacting. Thus, a method to simply check the current status of the system is important to provide control mechanisms to the user. Consequently, a future smart home notification system has to display the current state of the system (e.g., using a status LED) and to provide opportunities for the user to check the current state on demand similar to the Visual Information-Seeking Mantra [40]. For example, a robotic vacuum cleaner could use a status led as an indicator that device is not malfunctioned. In addition, an app could convey more details which users can access on-demand.

7.2 Present notifications in opportune locations at opportune moments.

Non-urgent notifications do not need an immediate action by the user. We observed in the Context theme that participants dismissed notifications received on their phones at inopportune moments or locations and forgot about them afterward. Previous work investigated reducing negative effects caused by notifications through delaying notifications to opportune moments (i.e., breakpoints) [16, 32, 42]. Particularly in the smart home context, the user’s location is important since certain actions can typically only be performed when at home. A future smart home notification system should notify based on the user’s current activity and location, i.e., when the user can immediately attend and react to an incoming notification. A smart home notification system could display notifications about taking out the garbage in the evening when the user is at home and preparing for a walk, and not in the morning when the user is busy and preparing for the day.

7.3 Consider notification blindness.

Developers of future smart home notification systems have to consider notification blindness. In the interviews, participants explained that they overlooked persistent notifications on their smartphones since they got used to them and did not read the text anymore; as we observed in the Situatedness theme. This shows that users already started to become notification blind on their mobile devices; similarly to display blindness for public displays [30]. In contrast, notifications displayed on the object were experienced as easier to perceive, more subtle and more actionable (cf. Situatedness). Therefore, developers should consider displaying notifications directly on the smart home devices, e.g., using ambient light displays. However, a smart home notification system needs to take the location of the smart home device into account. While on-object notifications, e.g., using ambient lighting or sound, might be useful for devices placed in frequently visited areas, on-smartphone notifications, or a central smart home display are more appropriate for devices located in less frequent visited areas, e.g., the basement.

7.4 Discretize continuous events.

Future smart home notification systems should keep the number of notifications low and inform users only when their attention is necessary. While the data generated through sensor is typically continuous, participants preferred discretization into a small number of events; as we observed in the Situatedness theme. Smart home devices should take care of the incoming sensor events and notify the users only if necessary, e.g., when users have to perform a certain action (i.e., descaling the coffee machine).

7.5 Combine related notifications.

To notify users only when their attention is required, smart home devices should further reduce the amount of triggered notifications by grouping related information over the day. For example, a smart fridge could collect information about the stock until the user will leave the house to go for grocery shopping in the afternoon. Instead of notifying users as soon as missing items in the fridge are recognized, the fridge would combine the notification and notify users in an appropriate moment such as the time they go grocery shopping.

8 CONCLUSION

In this paper, we investigated the design of non-urgent notifications using a smart plant system as a research probe. As no design guidelines for smart plant systems exist, we ran focus groups to understand how the apparatus needs to be designed. The focus group findings were used to identify independent variables for an eight-week in-situ study: notification display location (i.e., directly on the smart system vs. on the smartphone) and notification strategy (i.e., displaying the notification event-based or persistently). On-object notifications were significantly favored over notifications received on the smartphone and appreciated as more actionable.

Based on the results, we derived five design guidelines to display non-urgent smart home notifications: (1) The smart home system has to provide opportunities for the user to feel in control and (2) has to inform the users at opportune locations in opportune moments. (3) Developers of smart home notification systems have to consider notification blindness, e.g., by displaying notifications directly on the smart home devices. (4) Smart home notification systems should discretize continuous events to gain the user's attention only when necessary. (5) Smart home systems should collect similar kinds of information and notify the users only once per day.

The qualitative feedback suggests that the design guidelines apply to a large class of smart home devices that inform about non-urgent information. Hence, with this work, we provide designers and practitioners with guidance for designing smart home systems that remind users from time to time to pay attention to the system. Future work should investigate the design of systems that support notifications from different smart home devices with different levels of urgency.

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